A framework for the design and evaluation of magic tricks that utilises computational systems configured with psychological constraints

by

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To Lucy

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Statement of originality

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Abstract

A human magician blends science, psychology and performance to create a magical effect. This thesis explores what can be achieved when that human intelligence is replaced or assisted by machine intelligence. Magical effects are all in some form based on hidden mathematical, scientific or psychological principles; the parameters controlling these underpinning techniques are hard for a magician to blend to maximise the magical effect required. The complexity is often caused by interacting and conflicting physical and psychological constraints that need to be optimally balanced. Normally this tuning is done by trial and error, combined with human intuitions. This thesis focuses on applying Artificial Intelligence methods to the creation, and optimisation, of magic tricks exploiting mathematical principles. Experimentally derived, crowd sourced, data about particular perceptual and cognitive features is used, combined with a model of the underlying mathematical process, to provide a psychologically valid metric to allow optimisation of magical impact. The thesis describes an optimisation framework that can be flexibly applied to a range of different types of mathematics based tricks. Three case studies are presented as exemplars of the methodology at work, the outputs of which are: language and image based prediction and mind reading tricks, a magical jigsaw, and a mind reading card trick effect. Each trick created is evaluated through testing at public engagement events, and in a laboratory environment. Further, a demonstration of the real world efficacy of the approach for professional performers is presented in the form of sales of the tricks in a reputable magic shop in London.

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AI	Artificial Intelligence
GA	Genetic Algorithm
SA	Simulated Annealing
BA	Branching Anagram
Effect	The magical effect produced by the performance of a trick.
Method	The set of techniques used to produce a magical effect.
Trick	The overall performance and method that leads to a magical effect.
Spectator	The audience for a trick.
Performer	The magician, who performs a trick.
Designer	The designer of a magic trick.
Prop	An object used during a performance.
Gimmick	An object used during a performance that appears normal, but has been altered to secretly perform a function in the trick.

Chapter 1

Introduction

This thesis focusses on the creation and optimisation of magic tricks using a developed **framework**, based on observations of psychological phenomena that inform computational search and optimisation techniques. The framework provides an evaluation methodology, and suggests a simple validation measure of the outputs.

1.1 Overview

Magic, as a performance art, has been around for thousands of years [1]. The secretive nature of the practitioners of the art is well known [1]. This desire to keep the magical techniques out of the public consciousness has arguably led to the **performers** of the tricks, the magicians, being more widely known than the inventors of the tricks (not always the same magicians). **Trick** design is fundamental to the art. Typically, a breakthrough in a particular underlying **method** will disseminate through the magic community, resulting in many new tricks and performances based around the same core idea.

1.1.1 Elements of magic

The performance of any magic trick is critical to its success. The **design** of the trick itself - the set of methods, and physical objects (**props** and **gimmicks**, to be discussed later) - that must be deployed for a strong **effect** (a seemingly magical event), is equally important. The **perception** of a trick by a **spectator** can be influenced by both of these factors, and by the spectator themselves. For a trick to have a strongly magical effect there must be a cohesive interaction between these three elements: a trick's **designer**, performer, and spectator.

There exist many different versions of the same basic tricks; often different methods will result in the same effects. Trick designers have traditionally combined and recombined methods to create new tricks. There may be optimal configurations of methods for a given effect.

Spectators' perception of magic tricks is influenced in various ways by the performers. The set of underlying psychological phenomena being manipulated may not be well understood by either the performer or the designer of a trick, though the method and performance will be known to be effective. If the underlying psychological phenomena can be identified, it may be that there is a set of methods that optimally exploit it.

Some tricks are harder to perform than others. Magicians are willing to go to great lengths in pursuit of a stunning effect, though there may be sets of methods that optimise the physical and psychological effort required for a trick; these improvements allow performers to expend more energy on the theatrical aspects of a trick, such as narrative.

1.1.2 Optimising magic

Human trick designers are exceptionally good at intuitively optimising the various elements of a magic trick. However, sometimes a trick's design will present problems that are challenging for even the most ingenious of humans. Often these problems will be combinatorial in nature, or involve the trawling of large amounts of information in search of particular items.

As will be discussed in detail, computers can be configured as exceptional search and optimisation engines, able to explore large state spaces in search of optimal solutions to defined problems. Their use as an assistant in the trick design process is a previously unexplored domain, that appears to offer a rich vein of possibilities.

Psychological research outputs reliable data about particular mental phenomena. This kind of data can be integrated into computational systems configured to search for certain patterns and objects for use in magic tricks. The data can also be used by a human trick designer to inform the design process. The data used may be related to either the spectator or performer of a magic trick, or in certain cases both.

1.1.3 Evaluating magic

Psychological experience is difficult to categorise. Measuring the effectiveness of magic provides a particularly difficult case, due to the somewhat nebulous concept of a magical experience, and its inherently subjective nature, that may or may not lead to an entertaining experience.

1.1.4 Interest for new magic tricks

Magicians are always interested in new tricks to perform. The market for novel methods and presentations can be seen clearly in the myriad magic shops, both physical and online, around the world.

1.1.5 How magic tricks are currently designed

Magic tricks are traditionally designed by ingenious human inventors, such as Robert Harbin, U.F. Grant, Fred Braue, Alex Elmsley, and many more; knowledge of fundamental techniques is passed between magicians and designers, under a widely observed code of secrecy forbidding the dissemination of information to the uninitiated.

As we shall see in the next chapter, designers sometimes deploy computers to aid the trick design process in much the same way that writers may use word processing software, or film makers video editing software - for example, stage illusionist designers use computer-aided design (CAD) packages to design large on-stage props.

1.1.6 An approach to trick design

This work presents and investigates a conceptual framework for the design, optimisation, and evaluation of magic tricks that aims to integrate the various elements of magic discussed, including the addition of a computational component that is intended to provide solutions to problems that are unavailable to human designers. The role of the computer in the proposed framework is seen to be critical, allowing trick designers to move a large degree of responsibility for a trick's design to the software.

As we will see, configuring a computer to perform this kind of role is neither simple, even with modern Artificial Intelligence (AI) techniques, nor fully realisable. Creative computers able to specify their own parameters, and produce entirely novel categories of artefacts for human consumption, are some way off. Computers that assist the design process in a given domain in significant ways, some of which appear to mimic aspects and outputs of human creativity, are feasible. These are the kinds of computational system focussed on in this thesis.

1.2 Key questions to be answered in this thesis

The development of the proposed framework raises a number of key questions to be answered:

1. How can the human perceptual system be manipulated and affected by both external physical, and internal psychological, processes to produce magical effects?
2. How can human perceptual systems be modelled mathematically and/or computationally in order to optimise magical effects?
3. What are the implications of using modern computational devices, such as mobile phones, in magic performances?
4. Can computational systems take on large areas of responsibility in the design process of a magic trick, towards being seen as creative entities in their own right?
5. How can magic tricks be reliably evaluated?

1.3 Contributions

The main contributions of this thesis are:

1. The proposal and analysis of a new conceptual framework for the design, optimisation, and evaluation of magic tricks.
2. To the author's knowledge, the first use of AI for the design of magic tricks.
3. The proposal of a practical and principled approach to evaluating magic tricks.

1.4 Development of the framework

The framework under discussion, and in use, over the course of the thesis has been developed in tandem with the tricks that it outputs. The basic structure of the framework, to be detailed in chapter 4, took shape when the various elements of a magic trick were identified, and it could be clearly seen that a set of optional modular components would be beneficial.

The idea that an overall framework can be used to create new, or optimise existing, magic tricks, in a way that incorporates computational systems, was explored and tested with each new trick that it developed.

1.5 Publications

A paper describing the overall framework approach, and its application to create two new tricks (detailed in chapters 7 and 8), has been published in the peer-reviewed journal Frontiers in Psychology [2].

A paper based on the jigsaw trick, detailed in chapter 7, remains, at the time of writing, in review at the Taylor and Francis journal Applied Artificial Intelligence.

A paper based on the combinatorial card trick, detailed in chapter 8, remains, at the time of writing, in review at the Elsevier journal Artificial Intelligence.

1.6 Conclusion

This thesis presents a novel framework for the design, optimisation and evaluation of new and existing magic tricks, that integrates psychological observations, known and new magical methods and technologies, performance considerations, and computational techniques.

1.7 Outline of the thesis

Chapter 2 discusses and assesses the existing set of knowledge relevant to magic tricks and their creation, an analysis of different types of magic, and the scientific study of magic.

Chapter 3 discusses computational techniques in the context of creative systems, and the evaluation of entertainment and art.

Chapter 4 introduces a novel framework for the creation and optimisation of new magic tricks using computers configured to operate on data of observations of human perceptual and cognitive systems, with an incorporated evaluation methodology for the assessment of magic tricks.

Chapter 5 presents a case study in miniature, demonstrating the viability of optimising the magical impact of tricks through observation of psychological factors, and the feasibility of presenting a magic trick using a mobile phone.

Chapter 6 presents the first of three case studies demonstrating the proposed framework in operation, focussing on the creation and optimisation of language based tricks, and the development of the framework components.

Chapter 7 presents the second case study, building on the work done on the language based tricks, expanding the role of certain components of the framework, towards automation. The created trick is turned into a physical product and sold at a reputable magic shop in London.

Chapter 8 presents the third and final case study, a project that fully exploits the potential of the framework approach to designing and optimising magic tricks.

Chapter 9 presents conclusions about the framework approach, and adds some thoughts for future work at the nexus of magic, psychology and computing.

Chapter 2

Literature review: magic and science

The following chapter presents an overview of magic - its origins and forms - and outlines key works in the scientific study of magic. This overview provides the context in which the framework under discussion has been developed. The main theme that is being investigated is the knowledge that is necessary to generate new magic tricks, using a particular approach. As the thesis synthesises a number of large topic areas, the chapter is broken into various sections that provide an individual overview of each topic in the context of an overall theme. The topics covered in this chapter are: the origins of magic, types of magic tricks, and the scientific study of magic.

2.1 Magic

2.1.1 A brief history of the origins of magical performance

To understand the current state of magic, it is necessary to give a short overview of the origins of magical performances, and how magic has been able to progress in sophistication over the centuries, remaining relevant and of interest to spectators. The performance of magic, both on-stage and off, has a long and rich tradition in cultures all over the world. Burger et al [3] recount major advances and topics of interest in western stage magic from the eighteenth century to the present day, including discussions on magician's key roles in 1920's Hollywood, the performance issues for magician's assistants, financial aspects of magic performance from eighteenth century London through to modern day Las Veags, and the delicate relationship between magic and religion. Christopher and Christopher [1] lay out a breadth and depth of historical knowledge on what kinds of effects have been developed in many fields of magic, which points the way to areas in which new effects might lie. There are numerous categories of tricks, and endless variations within these categories; new effects are constantly being devised.

Christopher and Christopher [1] note that the origins of magic lie in primitive societies. Unfortunately, magical arts have historically often been used not purely for entertainment and enjoyment, but for nefarious purposes, preying on the gullible. They have also been associated with the occult, and used by those wishing to be worshipped as Gods or Goddesses. Christopher and Christopher [1] describe a number of examples throughout the last three thousand years. This phenomena is evident relatively recently: Randi [4] describes instances such as the Fox sisters (fraudulent Spiritualists), and Psychic Surgeries (pseudoscientific medical frauds). Randi provides rich material describing the exposure of charlatans in favour of "honest liars": bona fide magicians who tell the audience they are about to deceive with trickery, and then proceed to do so. Magic itself has long been a tool for enlightenment rather than exploitation; as Beckmann, an eighteenth century professor of economy at the University of Gottingen points out, it is "a most agreeable antidote to superstition" [5]. It is clear that the development of new tricks should be done responsibly, without redress to supernatural ideas or arguments, of which there is no need; indeed, in today's enlightened age these crutches would be detrimental to the credibility of any novelties produced.

Christopher and Christopher [1] describe the first known record of magicians operating as entertainers: the Westcar papyrus, which shows hieroglyphics written in 1700 B.C. about an Egyptian King, Cheops (thought to have built the Great Pyramid), whose sons describe to him various unverifiable magical effects performed by a number of magicians, notably Dedi, approximately five thousand years ago. Magicians contemporaneous to those described in the Westcar papyrus are thought to have been at work in Babylonia, India and China. The first representation of an actual magical effect was found inscribed on a wall in Beni Hasan, Egypt. The drawing is thought to have been made in 2500 B.C., and shows a picture of a cups and balls routine; an effect still performed by magicians today. Christopher and Christopher [1] note that there is strong evidence of magicians and conjurers performing as entertainers in Spain, Italy, Turkey and Greece two thousand years later.

Christopher and Christopher [1] further describe the account of a Dr. Handsch, a physician who documented the feats of an Italian Knight, Girolamo Scotto, who entertained Archduke Ferdinand and friends in 1572 with the first recorded mental-magic routine. Mental-magic is a branch of magical effects that rely on the conjurer appearing to be able to know the thoughts of others in the absence of any obvious communications. Dr. Handsch recounts Scotto asking Philippine, Ferdinand's wife, to think of any coin from a heap on a table, and proceeding to find it.

Another magical effect, still in wide circulation today, in which selected playing cards are placed in a deck and caused to rise from the pack seemingly at merely the wish of the magician, was first attributed to another Italian from the same period as Scotto: Abram Colorni, a court engineer. What is interesting to note is that more than four hundred different ways to perform the trick have subsequently been invented [6].

The first books detailing how certain tricks can be performed started appearing during the sixteenth century. These books, rather than recounting a magical effect as remembered by a spectator, detail the methods behind the deceptions. Jean Prévost's La Première Partie des Subtiles et Plaisantes Inventions appeared in Lyon, France, in 1584. The Discoverie of Witchcraft, from the same year, by Reginald Scot, published in England, enlightened those of the time who held the idea that many sleight of hand tricks were in fact of a supernatural nature. Later, 1612's The Art of Jugling, signed Sa. Rid. (presumably an abbreviation), was the first text published in English entirely devoted to describing the methods behind magic tricks [1]. What is important about the appearance of books of this nature is that for the first time the explicit conjuring methods had been documented; previously, knowledge in this domain had been passed on by word of mouth.

In 1770, the world was introduced to Baron Wolfgang von Kempelen's chess-playing automaton: The Turk. This machine, built in Hungary, was a desk behind which sat an apparently mechanical man, that seemed able to play a good game of chess of its own volition; an apparently thinking machine. The device caused a storm of controversy, and was, for over fifty years, the subject of a great deal of speculation from leading thinkers of the time as to its method of operation. While presented as an automaton, able to operate independently, it was in fact an elaborate trick, enabled by the presence of a man inside the machine itself, who played the games of chess both intellectually and physically [7]. What was beguiling to the audiences of the time was the idea that a machine could exhibit human-like intelligence, independently of humans; an idea still seductive today. In the eighteenth century, a thinking machine was the ultimate illusion.

The proliferation of knowledge, due to the documentation and dissemination of its techniques and technologies, led to many innovations, and the birth of many star performers over the subsequent years, through to the present day: Robert-Houdin, Kellar, Thurston, Ching Ling Foo, Le Roy, Goldin, Carter, Houdini and Dunninger to name but a few. Crucially, the recording and sharing of knowledge about magical methods has enabled the creation of new and ever more sophisticated techniques.

From the origins of magical performance outlined above, a rich culture of magic has grown, a key feature of which is that contemporary audiences are always one step behind contemporary magicians, in terms of technological understanding of what is possible, and in understanding the extraordinary lengths magicians are prepared to go to in order to realise a magical effect. In fact, this idea of being one step ahead is commonly identified by magicians as being the key component in a successful magical performance, as Stajano and Wilson [8] have noted in their work on the principles underlying many modern day scams and frauds - as Randi [4] and Beckmann [5] point out, magicians are a kind of honest liar, always one step ahead of the audience, where the pay-off is entertainment rather than personal gain.

As Christopher and Christopher [1] make clear, the popularity of magic and magicians remains undiminished. Modern magic is a form of entertainment currently enjoyed throughout the world.

2.1.2 Tricks of the trade

While the personalities involved in the performance of magic are of course critical, not least because they are often the inventors of their own tricks, the focus of this thesis is the tricks themselves. Major tricks and techniques have evolved over the years, gradually converging to a set of basic techniques widely known inside the magic community. Magicians and trick designers are constantly striving to find new tricks, as Fischer [9] notes:

> Even though old ideas keep turning up, new blood is always flowing into card-conjuring. It is and always must be an inexhaustible field.

What applies to card-conjuring, equally applies to magic as a whole.

Below, four broad categories of magic are outlined: large scale magic (often on a stage in a theatre), close up magic, geometrical tricks, and mentalism.

2.1.2.1 What is a magic trick?

There are a two components that constitute a magic trick. The most fundamental is what is known as the effect: the moment that magicians hope will inspire wonder. As Ortiz [10] notes, an effect occurs in the mind of a spectator. Lamont [11] describes one of the most commonly performed magical effects, the vanish: most people will have seen someone make a coin vanish from their hand. This is one of a number of basic magical effects that magicians are able to achieve; others include, appearance: an object seems to impossibly come into existence; transposition: an object miraculously moves in space; transformation: an object is changed to another form; restoration: a previously destroyed object is reconstituted; penetration: the impenetrable is breached. An object, in this context, can be a physical object, or a piece of information; for example a playing card, or a spectator's date of birth. Essentially, an effect is an event that the observer perceives as being something outside of the normal physical rules of the world [11].

Often, effects will be achieved by a sleight of hand, or a device utilised by the magician; sometimes, an effect can be achieved by misdirection, or by exploiting a certain property of human perception. Whatever particular approach is used to create a specific effect, this mechanism, the second component of a magic trick, is traditionally referred to as the method [10]. Often, there will be a critical moment in a trick that requires what is known as a move; for example, imperceptibly shifting an object from one hand to another. Covering this move so that the spectator is unaware of it is vital. Magicians will commonly cover a small move, that performs some necessary action, with a larger move, that distracts the spectator [10].

These two elements, effect and method, are what constitute a magical performance. The effect is experienced by a spectator, and generated by a performer with some method usually covered by a move. Another important factor in a trick is how the spectator remembers the events that occur during its presentation. There may be parts that the performer would like the viewer to recall clearly, and others less so. For example, the effect may rely on the spectator remembering that a deck of cards has been shuffled (even if, in fact, the shuffling is only an illusion and the deck remains in its original order). To achieve these strong memories, a performer may use what is sometimes referred to as anchoring [10] [12] - essentially making a particular element of a trick stand out for the spectator; in some senses, the opposite of misdirection. However, for a magician to simply state that a deck of cards has been shuffled would be risky, as it invites the viewer to question this. Better that the event is highlighted indirectly, perhaps by the performer pointing out that shuffling a deck of cards is difficult with their hands over their heads.

For an observer, as Burger [13] shows, the narrative is a particularly important aspect of some, if not all, magic tricks. Ortiz [10] elucidates how many tricks rely on some kind of story arc to maximise their psychological impact, and how the impact of a trick varies enormously due to its presentation. The narrative can be a critical element of the method, tying together moves, anchors and any other deceptions the magician deploys. Ortiz [10] makes clear that carefully crafted storytelling not only provides a narrative context within which the performer can present a sequence of events to an audience in a way that is easily comprehensible, but also allows space and opportunity for various misdirections and sleights, the mechanics of a trick, to be executed. Traditional texts on narrative such as Lamb [14] highlight that storytelling in the context of a magic trick should not be confused with conventional storytelling - the goals and intentions of the story are often different. A magical narrative leads inevitably to a moment of wonder. The story serves this end product, a point at which the audience witnesses something that is counter-intuitive to their normal understanding of how the world works, causing them to question what they have seen.

Ortiz [15] postulates that strong magical effects usually involve the tight interweaving of narrative with seemingly impossible events, where the seeming impossibility relies on elements of the story, and the story relies on the effect. After witnessing a magic trick, most rational spectators do not believe something supernatural has occurred, rather they find they are simply unable to provide an explanation for the events they have witnessed, and subsequently derive some enjoyment from this predicament. While most people are unable to adequately explain the laws of quantum physics, either to others or themselves, they gain no pleasure from this; what makes a magic trick enjoyable is its presentation, the narrative framework within which the unexplainable, the effect, occurs.

Neale [16] shows that magic as a cultural entity, something that individuals in a society, and therefore societies as a whole, attach meaning to, and relate to in various philosophical ways, establishes the form as something unique and additional to traditional entertainment. Magic's inherent ability to persuade a spectator to question the nature of the reality that their mind constructs for them places it firmly in the same intellectual tradition as surrealist visual artists such as René Magritte and Salvador Dalí [17], and the poets André Breton and Paul Éluard [18].

Fitzkee [19] provides a kind of lexicon of components that can be combined to form a compelling magic trick. He describes known methods and techniques that a magician may employ in the construction of an effect. This type of thinking is critical to this thesis, as it regards the design and implementation of magic tricks as fundamentally a process of combination and recombination of existing knowledge; the individuality of each new trick being the stamp that the magician is able to provide, either during performance, or some novel ingenuity of design. To illustrate the breadth and depth of what a magician may achieve with the right mental and physical tools, various categories of trick are now discussed.

2.1.2.2 Large scale magic

Stage magic refers to tricks performed by a performer in a theatre of some kind - the tricks themselves are often large in scale. Mayne [20] shows that this type of trick is intimately related to technology, detailing many ways to build and use various on-stage devices. Physical objects used in a trick, **props**, are at the heart of a lot of stage based magic. A prop can be simply a necessary object to perform a trick (e.g. a deck of cards in a card trick). Ingenious contraptions that provide the core mechanism for the magical effects on view, **gimmicks**, a specific term in magic, are objects, sometimes visible props (gimmicked props), that perform some secret, unseen, function during a trick - many such items are highly sophisticated. The key point to note is that magicians often offload much of the workings of a trick to various objects during performance: mirrors, false doors, secret compartments, clever lighting, and many others. Mayne also discusses the subtle cognitive and perceptual effects that can be produced with careful placement and adjustment of objects; for example, a table may appear slightly larger or smaller than it really is, depending on how it is painted, or the colour of the background image used on-stage.

Tricks such as the The Vanishing Lady, The Zig-Zag Lady and The Moth are prototypical models of stage illusion technique, all described in detail by Mayne [20]. These tricks are based on a wide range of intuitively determined cognitive and perceptual errors experienced by an audience, and are the result of centuries of experimentation on the part of magicians, who obsessively hone their on-stage props and gimmicks to perfection. Each trick is contained within a compelling story, to better serve the illusion; none are presented as feats of engineering, though they all are. All of the invention and innovation is necessarily hidden away. What the audience sees is a piece of drama, ending with a seemingly impossible event.

Steinmeyer [21] describes the operation of a number of famous effects, often produced using a combination of mechanically sophisticated objects carefully stage managed to produce a magical effect; for example, in one particularly complex trick, a donkey is seemingly made to vanish before an audience's eyes.

As Rao and Narayan document [22], many Computer Aided Design (CAD) packages are available that assist humans in designing physical objects for various purposes in manufacturing and engineering. Tim Clothier uses these types of computational representations of the physical world for designing magical props [23]. The key point is that computers have a role to play in many aspects of trick design.

Often, techniques and technologies developed by magicians will be taken up by other industries: the early development of cinematic techniques is perhaps the most interesting example. Solomon [24] shows that the birth of cinema, and associated cinematic techniques, is closely woven with magic and magicians. Film itself is somewhat of a magic trick that relies on cognitive information processing to construct the illusion of movement from a sequence of static images presented at twenty four frames per second. George Méliès and Harry Houdini were early pioneers of trick cinema, in which the already present illusion of cinema was built upon to actually depict seemingly impossible events on screen; various photographic techniques were utilised to fool audiences. Today, special effects are so widely deployed, and consequently understood by the general public, that any kind of trick cinema has fallen out of favour. As shown previously, no magical effect is possible if the audience believes they know the explanation for the effect.

2.1.2.3 Close up magic

Close up magic, often performed by a magician for just one person, relies on cognitive and perceptual errors induced in an audience by a magician using techniques of misdirection and sleight of hand. Often, props and gimmicks are used. A paradigmatic example, using only a simple coin, that is based entirely on perceptual and cognitive errors, is the French Drop shown by Charles [25]; a sleight of hand, combined with an act of misdirection for reinforcement, whereby an object is seemingly transferred from one hand to another, but in fact remains in its original position, for further manipulation by the magician.

Card magic is a particular branch of close up magic that has a long history, and as such is both broad and deep in its varied effects and methods. As with other areas of dexterity based magic, many card tricks can be mastered only after hours of practise; an alternative application of such skills can be profitable, as shown by card sharps at the gambling table. It is often assumed that card tricks rely mainly on the speed at which the cards are manipulated to hide the method; however, this is not the case. As with other areas of magic there are many methods that rely exclusively on cognitive quirks and errors for their efficacy.

Erdnase [26] and Hugard [27] provide key texts on card magic, describing many classic effects that can be produced, along with the various basic card manipulation techniques that must be mastered by a working magician: lifts - secretly removing known cards from a deck; false deals - unfairly distributing cards in a seemingly fair way; side slips - a technique to bring a card to the top of a deck; passes - swapping portions of a deck to bring a selected card to the top; palming - secretly moving a card from a deck to a hand; false shuffles - apparently randomising a deck while maintaining some order; changes - the illusion whereby a turned over card changes value; crimps - marking cards; jogs - protruding cards in a deck; and reverses - flipping over selected cards in a deck. The issue of forcing is also addressed: a key technique whereby a magician will make sure that a spectator picks a particular card of their choosing. There are various methods to achieve this - for example, if a skilled magician fans a deck of cards in front of someone and asks them to pick any card, they are able to literally move the fanned deck into position as the spectator makes their choice, thereby forcing a particular card to be chosen - the skill is in making this move undetectable.

Trost [28] details a wide range of card tricks available to magicians. This is just one example of numerous books dedicated to describing card magic, and contains many accounts of interesting effects and techniques.

Mactier [29] details a large number of mathematics based card tricks, which often require little if any sleight of hand. Tricks that genuinely need no manual dexterity on the part of the magician are known as self-working magic tricks. Mactier's focus is on the numerical and sequential properties of playing cards, and the way in which these properties can be manipulated for magical effect. Ordering a deck of cards in a certain way, often to be memorised, can enable a magician to create the powerful illusion that they are able to read a spectator's mind, by working out a card a spectator is holding, or is at a certain position in a deck. Combined with the many, order preserving, false shuffling techniques available, skilled magicians are able to perform seemingly impossible feats.

Many of Mactier's [29] tricks rely on the set of observations known as the Gilbreath [30] principles. These remarkable findings by Norman Gilbreath in 1958 show that a deck of cards, ordered in pairs of red, then black, throughout, maintains, after one special riffle shuffle (performed by splitting the deck in two, reversing the order of one portion, and interleaving the cards back together), the property that all sequential pairs in the deck are guaranteed to be composed of one red and one black card. Further, this property holds for any number of sequential objects; thus, for an imaginary deck made up of cards of four colours (perhaps red, black, green, blue), if the whole deck is ordered in groups of four in the same repeating order, after one riffle shuffle (with half the deck reversed in order), each group of four dealt from the deck is guaranteed to contain one card of each colour.

Mulcahy [31] details a very large range of mathematical card tricks, encompassing many fundamental techniques. Bourdreau [32] provides an extensive investigation into tricks based on structured decks of cards, for the purposes of card prediction and apparent mind reading. Many of the tricks are based on, or related to, cyclical De Bruijn sequences - cyclical sequences of objects in which each unique subsequence of a given length appears once - described by Diaconis [30] and Chung [33].

What is interesting about mathematical card tricks is that they are essentially based on abstract processes and arrangements of cards, that, mechanically followed, will result in something that a magician can rely on: a particular card in a particular place in the deck, or a spectator holding a certain number of cards, and so on. These abstractions and processes, it should be noted, are ideal objects for computers to deal with. Their combination and recombination to form new effects is the type of task a machine should be able to systematise and operate upon. Generally, this task currently falls to diligent and ingenious human designers.

Card magic is varied and diverse, of much interest to spectators and magicians alike. Notably, magicians do not always rely on sleight of hand and card manipulations to perform magic with a deck of cards, though these techniques are common.

2.1.2.4 Geometry and illusion

Self working magic tricks are not limited to card magic. Often they can be based on geometrical properties of the physical world as experienced via the human perceptual system. Gardner [34] shows many tricks that rely directly on both physical properties of the world (specifically geometrical properties), and properties of the human visual perceptual system.

Fechner [35] describes geometrical illusions that have been studied to determine, as with studies from Morgan [36], what can amplify or ameliorate the effect. Illusions seem to illustrate powerful constraints upon visual processing, arising when subjects are instructed to carry out a task to which the visual system is not adapted. Often the specific perceptual and cognitive processes involved are unknown, or at least not rigorously defined, as the working out of the physical properties of a trick often points out a more general perceptual or cognitive failing or quirk, rather than the other way round. This tends to be true of most magic tricks: the inventors find the gaps in human perception that can be exploited in an intuitive, rather than scientific, fashion. Tognazzini [37] presents work done on using this intuitive knowledge as the foundation for more formal approaches to various problems, for example in the field of HCI (Human-Computer Interaction), where studies of the various perceptual properties of magic tricks have been applied to inform and improve interface design.

As with stage magic props and mathematical card tricks, the salient point is that the mathematics based illusions described by Gardner can be readily de-constructed into forms that can be worked with computationally.

2.1.2.5 Mentalism

Mentalism is a branch of magic that relies on a magician divining seemingly impossible pieces of information, often secretly held by a spectator. For example, a magician may appear to use the power of their mind to correctly state a stranger's exact place, and time, of birth. The techniques deployed by so called mentalists are varied, and of all the branches of magic, the most perniciously deployed. There are, of course, many honest mentalists. Derren Brown is a famous contemporary entertainer who uses certain techniques from this area. Brown also uses various cognitive techniques such as suggestion and hypnosis to create astonishing effects [12].

Annemann [38] provides an excellent overview of many of the basic mechanical techniques deployed by modern mentalists. Billets, writing, bits of paper, and sealed envelopes feature heavily in Annemann's work. Props and gimmicks are used in a lot of mental magic effects, often secretly and ingeniously recording and transporting information from one place and time to another. The techniques of misdirection and sleight of hand common in card and close up magic are combined with narratives that emphasise the apparently supernatural nature of the magician's own mind to produce a mysterious effect, often bestowing seemingly telepathic powers on the performer.

Corinda [39] provides further documentation of the mentalist's art, showcasing: techniques and "Swami" gimmicks to secretly write or draw on paper or other materials; to muscle read - the subtle art of responding to slight movements in people's muscles in response to questions and suggestions; book tests - whereby a word, phrase or image secretly chosen by a spectator is revealed to an audience; memory tricks - the use of mnemonics and mental systems to perform seemingly impossible mental feats; predictions - apparently predicting the selections of a spectator; blindfold tricks - where a gimmicked blindfold is used for various effects; and a number of card tricks including a variation on the classic Princess card trick, the original of which will be discussed in a later chapter.

Earle [40] provides further evidence that a mentalist's toolkit extends well beyond the confines of his own mind. Extensive use of gimmicks and ingenious information passing methods form the backbone of much of this work.

As mentalism encompasses so many other areas of magical technique, from cards to stage props, aspects of it lend themselves well to self working effects, often mathematically based. Again, it is interesting to note that, as discussed, many of these abstractions and processes should lend themselves well to computational representation. Much of mentalism is a recombination of existing methods with a uniquely mentalist presentation that emphasises the mental powers of the magician.

2.2 The science of magic

Having outlined, with necessarily broad strokes, the various types of tricks that are possible, with some detail about their mechanics, it is important to discuss what is going on for an audience when they are performed, and how it is that magic is such a potent and reliable art form. Scientific analysis is the best known method for understanding how and why physical systems work. For the purposes of this thesis, to improve existing magical effects, or to generate new variations, it is essential to understand magic tricks as fully as possible. Therefore, the scientific understanding of magic and conjuring effects should provide the best possible way to study their psychological workings, stripped of the bias and intuition of individual magicians. Similarly, magic tricks can be studied with a view to improving our knowledge of how humans work, both cognitively and perceptually; explaining precisely why a certain trick is effective could tell us more precisely how aspects of human perception and cognition operate.

2.2.1 A useful endeavour?

Studying magic scientifically has been a subject of interest for some time - certainly, the application of psychological theories to magic was being investigated by Triplett [41] in 1900. It is difficult to determine the earliest rigorous scientific study of magic, though Jastrow [42] posted perhaps one of the first investigations in this area in 1897. Both these early investigations describe magic's efficacy as being closely related to its narrative powers: heightening the psychological impact of the magical effect by building to its climax, using various psychological methods along the way; for example, establishing the magician as the wielder of extraordinary powers by way of a number of small magical effects.

Many others have attempted a rigorous approach to creating a set of scientifically sound principles to describe the techniques involved in magic and conjuring: Binet [43], Hyman [44], and Kelley [45] have offered notable contributions. Binet used a chronophotographic gun (enabling the rapid recording of sequential photographic frames) to investigate sleights of hand used by magicians, revealing previously unknown perceptual mechanisms. Hyman analysed the psychology of deception, providing a historical overview, along with suggested categorisations and examples of the various type of deception, and a description of the formal properties of a deception. Hyman discusses the perception of causality and its relation to underlying mechanisms in magic tricks.

Nardi [46] approaches magic tricks from a sociological and social psychological perspective, analysing the similarities and differences between a magic performance and interactions during normal life. The work shows how a magician is able to construct an alternate version of reality by bracketing off parts of the performance, and setting up various visible and concealed "tracks" of events, in order to control and undermine people's expectations, and their normal rational view of the world.

Wiseman [47] laid out some foundational works towards a psychological theory of deception, before Lamont and Wiseman [11] made an effort, supported by interviews with leading magicians, to explain the theoretical and psychological underpinnings of conjuring tricks, outlining a number of rules and fundamental techniques that can be used for effective performance. For example, they provide a thoughtful overview of why, from a psychological perspective, subtly but visibly presenting a false solution may be effective in diverting a spectator's attention away from the real method.

Macknik [48], and Martinez-Conde and Macknik [49] [50] [51], started work in recent years to produce explanations of magical effects in terms of cognitive neuroscience. Clearly, when the brain perceives a trick, some physical process is taking place within the brain that results in the conscious perception of the trick, and subsequent phenomenological experience of surprise or wonder - usually due to some incorrect inference about the state of the world that causes a conscious notion that the normal rules of the world have been violated. What these physical, neuronal or otherwise, processes are, and how they function, is of wide interest. The perception and experience of magic tricks is just one window into the complex and labyrinthine human brain. It is of interest to question what magic can teach us about the brain and how it processes information relating to physical and psychological events, but also what these same information processing systems can tell us about possible new magical effects. If the neurological processes at work during perception can be well understood, it follows that they could also be well exploited by knowledgeable magicians. Currently this research is of only minor interest to a designer wishing to construct new tricks, as it is currently at a stage where the insights gained from lower level cognitive neuroscience, into the higher level psychological functions of the human mind, are less sophisticated than can be intuited by magic designers themselves; in fact, currently, the information is mainly flowing in the other direction: magicians are providing insights to the scientists.

Kuhn [52] has started work towards postulating a general science of magic, a way of describing magical effects from a scientific perspective, categorising and formalising the psychological processes at work. As we shall see, much work in this area provides concrete and measurable theories as to the general nature of human perception and cognition as it relates to magic tricks.

Parris et al [53] used neuro-imaging techniques to show that while perceiving a magic trick, certain brain regions associated with the detection of conflict and the implementation of cognitive control were more highly activated in the left hemisphere - further, viewing of magic tricks caused greater activations in these regions than viewings of surprising events (differentiated from magical events by the imposition of a magic condition: that a cause-effect relationship is violated); this suggests that the brain regions identified play a special role in causality processing, and constitute an element of the neurobiology of disbelief.

Magic tricks themselves have also been evaluated scientifically, as summarised by Kuhn and Rensink [54]. They remark that the use of appropriately controlled experiments to rigorously determine, for example, that a particular effect does or does not exist, may enable the underlying mechanisms, psychological or otherwise, to be determined. Three principles of trick evaluation are given:

1. Decomposition: a trick is decomposed into its constituent elements for analysis - each element of a trick's method is considered. This approach often illuminates the mechanics of a trick in new ways, and suggests new areas for further analysis; sometimes an individual component identified in this way may be worthy of its own detailed study.

2. Abstraction: moving from a particular trick's description, to a more general view of the techniques involved in the trick that may be used to instantiate other similar tricks. Olson et al show how [55] this abstraction process, and subsequent focus on the *key base factors* involved in a trick, allows for the easier control of a trick's method, and therefore easier control of its evaluation. The values that the key base factors may take on to maximise a given effect are also of interest here; Olson et al [56] give a careful analysis of the cognitive characteristics of playing cards that shows previously known groupings of cards, along with new groupings. Through

measurement and analysis of abstract tricks, Triplett [41], and Kuhn and Land [57], have shown previously unknown factors influencing the perception of the Vanishing Ball illusion.

3. Explanation: a magic trick, Kuhn and Rensink show, can, as with other phenomena of a perceptual or cognitive nature, be explained by the psychological mechanisms involved, the underlying neural explanations for these psychological phenomena, and the functional/computational theories as to why these mechanisms are as they are. More detailed discussions of these areas follow below.

There are opposing views as to the usefulness of studying magic from a scientific perspective, or framing a theory of magic in scientific terms: Lamont [58] suggests that it is in itself an illusion that a science of magic exists, arguing that the link between theories of conjuring and scientific theories of psychology have been exaggerated. The key factor for this thesis is the idea that it is plausible to understand, or at least measure, the perceptual and cognitive phenomena associated with a spectator's experience of a given trick.

Manipulating perceptions of reality is key to magic performances, so it is no surprise that, as we have seen, magicians have been intuitively exploiting these gaps in the perception and cognition of physical reality for centuries.

2.2.2 Perception

2.2.2.1 Illusion

The perceived nature of reality, both present and remembered, is a key area of interest for magicians and scientists. Gregory [59] [60] illustrates how the study of illusions is able to tell us a great deal about the nature of perception and the thin line that exists between that which is real and that which our brains invent for us. Although our experience of the world seems whole and continuous at each moment, much of our perceived world is in fact constructed by our brains. Features of the human visual perceptual system frequently operate in ways that lead to shifting perceptions of reality. For example: the Necker cube [61] is a line drawing of a cube that the brain is able to interpret with two different perspectives; the Müller-Lyer illusion [62] is the incorrect perception of one line as longer than an identically sized other, due to the ends of each line having two lines added in the shape of either an arrow head or a kind of two pronged fork (the arrow headed line is often perceived as the shorter); the rabbit-duck illusion [63] is a drawing of what can be just as easily interpreted by the mind as either a rabbit's or a duck's head. These ambiguities and illusions provide magicians with the opportunity to distort an audience's perception of certain scenes, perhaps to obscure some method, or to highlight a particular item on view.

2.2.2.2 Expectation

Our brain's expectations of the perceived world plays a large part in what we consciously experience, even when it differs from the actual reality of the situation; Bunzeck [64] shows that neural activations occur in the auditory cortex while visual scenes are displayed that would normally have accompanying sounds, but are in fact silent. Triplett [41] and later Kuhn and Land [57] developed and studied an illusion whereby a ball is tossed in the air a number of times by a magician, before a final simulated toss during which the ball is secretly retained in the throwing hand; large numbers of spectators report seeing a kind of ghost ball in motion during the final toss.

2.2.2.3 Attention

A key psychological factor in magic is attention, seen by Desimone and Duncan [65] as the process that enables our brains to selectively filter large amounts of incoming perceptual information, allowing us to make sense of and manipulate our environment in advantageous ways. This sophisticated and complex process can also lead to perceptual errors. Our eyes constantly rove over the visual scenes presented to them, in order to update various parts of the brain with the latest information; parts of the scene that are not currently fixated on are fabricated by the brain given its best estimation based on its last update from the eye. This process will be shown to be key to magic in many ways, as the areas of the visual field not attended to are ripe candidates for covert manipulation by a magician.

2.2.2.4 Looking without seeing

Blindness, somewhat related to illusion, is the absence of particular perceptual and cognitive states in the presence of certain stimuli. This looking without seeing is a core property of the observation of most magic. The observer is looking at the magician performing some routine, but despite this they do not perceive all of the events that occur before them.

Kanwisher [66] first described Repetition Blindness: a psychological phenomenon observed in people shown rapid sequences of words (Rapid Serial Visual Presentation, RSVP - approximately 150 millisecond intervals). A second instance of a repeated word is often poorly recalled, even if is displayed up to 500 milliseconds later in the sequence, with other words preceding it. Bavelier [67] shows that this blindness can also be induced using words and images, for example the word 'cat' and a picture of a cat.

A related phenomenon, attentional blink, first described by Raymond [68], occurs when a subject fails to detect the repetition of a certain visual stimulus when presented at between 180-450 millisecond after the first occurrence of the stimulus.

Change blindness, the inability to detect large changes in visual scenes without consciously attending to them, is a relatively large topic area that has been critically assessed by Simons[69]. Rensink [70] shows how the human perceptual system does not form complete detailed representations of visual scenes, and that attention is the crucial element required to perceive changes in an environment under normal viewing conditions. To determine this experimentally, Rensink uses a *flicker paradigm*: people are shown two images, A and A', with a blank screen interleaved between them for a short period. A and A' are identical, except for some small, or large, changes made by the researchers to A'. People struggle to identify even very large changes made to the scenes depicted in A'.

Mack and Rock [71] illuminate a key psychological phenomena that goes some way to explaining this: inattentional blindness - the inability of humans to consciously perceive things that they are not paying attention to. Simons [72] reports a fascinating experiment that illustrates inattentional blindness in a startling way: subjects are shown a scene of two groups of people, one dressed in white, the other black, passing a basketball around between them, and asked to count the number of passes. At the end, it is pointed out that during the course of the scene a person dressed in a gorilla suit had danced into view, stopped, turned around, and danced off screen. Few people report having noticed the gorilla, as they are too busy counting passes of the basketball. The key aspect to this is that the participants are focussed on a particular task: counting passes. The colour of the suits worn, while not critical, can accentuate the effect: passers of the ball wearing white suits may decrease the chance that an observer will notice the black gorilla that dances into view (mixed in with other people dressed in black suits).

A magician's success in secretly changing or moving objects during a performance may depend largely on their ability to surreptitiously move their spectator's attention around the scene they have created for their trick, be it a stage, or a deck of cards in their hands.

2.2.2.5 Misdirection

Attention can be manipulated by perhaps the most important tool available to a magician: misdirection - the art of moving an observer's attention away from a point of interest, allowing the magician to perform a move of some kind (slipping something into a pocket, swapping a card, etc).

The methods deployed by magicians to misdirect may be similar to abrupt visual onsets. Abrams [73] has shown that the onset of motion is capable of capturing attention. Coull [74] describes how temporal aspects of attention allocation have also been studied using FMRI imaging techniques; these temporal aspects are equally important as spatial properties. Yantis [75] shows that the assumed automaticity of visual attention due to abrupt visual change has been shown to be false under certain circumstances.

Misdirection - how attention can be purposefully manipulated - is not well understood. Kuhn and Martinez [76] provide an overview of the current thinking, from both magicians and scientists, on the role of misdirection in magic, and explanations of the basic principles at work. Kuhn et al [77] provide an extensive taxonomy of misdirection in magic, based on the perceptual and cognitive mechanisms involved.

Kuhn and Martinez [76] show that magicians themselves have proposed theories of how misdirection works, and what can be achieved with it. Sharpe [78] proposes two modes of misdirection, active and passive; essentially distinguishing between manipulating spatial attention by use of changing stimuli, and manipulating cognitive apprehension of static stimuli. Usually, in performance, a magician will perform a secret move, the method behind the trick, at the same time as a distraction, to cover the method. The distraction would normally be perceptually larger than the secret move. Kuhn and Martinez [76] describe creating zones of high and low interest. Robins [79] believes that misdirection is also about creating a frame of attention, outside of which events are more likely to go unnoticed; the smaller the frame, the more focussed the attention, and therefore the more effective the misdirection. Time misdirection - separating, in time, the method of the trick from the effect - is another form of misdirection widely deployed and discussed by magicians, notably Sharpe [78], Tamariz [80], Lamont and Wiseman [11] and Ortiz [15].

Kuhn and Tatler [81] and Kuhn and Findlay [82] have drawn attention to the similarity of misdirection to inattentional blindness; the case is not without its detractors: Memmert [83] and Memmert and Furley [84] point to gaps between inattentional blindness and attentional misdirection. Kuhn and Tatler [85] explain that distraction during misdirection occurs implicitly through the application of various misdirection principles; with inattentional blindness, the distraction occurs due to an explicit task (e.g. passing basketballs around).

Teszka et al [86] have used change blindness as a way to measure the efficacy of misdirection; if a subject's attention is drawn away from an area of change using social cues and questions, and they subsequently fail to notice the disparity in the expected way given previous results on change blindness, then the misdirection can be argued to have been successful.

Kuhn [82] investigates misdirection and eye gaze using sophisticated eye tracking systems. Covert and overt attention is differentiated. Where the eye is fixated does not necessarily determine that which the brain is attending to. Covert attention is that process whereby the brain attends to a different area of the visual scene than the one fixated on by the eyes.

The role of the live magician, in contrast to one viewed on television or a computer monitor, is illustrated by the face to face misdirections in Kuhn and Tatler [81] [87], contrasted with the computer monitor based experiments by Kuhn et al [82]; interestingly, the misdirection techniques, and therefore magical effects, are still successful on screen, though some differences are described. Generally, misdirection is more effective in a face to face situation. Social context also plays a role in eye movements, presumably due to the physical presence, or otherwise of a magician; watching a newsreader on a screen exerts significantly less social pressure for things such as eye contact or social cues as would their physical presence. The overall effect that social cues can have on misdirection methods is unclear, though it appears that the current balanced view is that they often play some role.

There is much work to be done to formalise and fully understand all the perceptual and cognitive mechanisms at work in misdirection, though there exists much that is of interest to those wishing to understand misdirection from both a scientific and magical perspective.

2.2.2.6 Psychophysics

Magic often relies on perceptual stimuli producing a certain experience for a spectator; for example, sawing a person in half on stage: the visual stimulus must be such that it really seems to the audience that the person inside the box is being sawn. Being able to measure and quantify the various factors that go into this type of illusion is of use to magicians, who will mostly create their props and gimmicks using a system of trial and error, until the desired effect is achieved. This can lead to inefficiencies.

Psychophysics is the scientific analysis of the relationship between stimuli and sensation, first initiated by Fechner in 1860 [35]; it is a rigorous set of methods designed to systematically analyse the effect of stimulus on perception. Most modern methods rely on some type of threshold detection [88] (the amount of a certain stimulus needed to produce a perceptual event), signal detection theory [88] (the description of the means by which a perceptual system is able to distinguish patterns from noise in a given signal), and ideal observer analysis [89] (the use of a theoretical system, that displays optimal performance for a specific task, to analyse psychophysical data).

Baird [90] illustrates how the human perceptual system is able to make accurate and discerning size and distance judgements, relative to its environment. When considering magic as a failure of the perceptual system, particularly with relation to geometrical magic tricks, it is useful to have a method of measuring when the perceptual system is unable to accurately determine certain stimuli changes. To determine the level of stimulus required to produce a certain event or sensation, the psychometric measure of *absolute threshold* is used:

> A threshold is defined by a convention. Usually, the convention is 50% probability of perception of a difference in luminance, quality (color), size, etc. [91]

From a magical perspective, it is interesting to note that stimuli can be changed without the perception of the stimuli changing to any large degree. The field of psychophysics was instrumental in the development of the data compression techniques that enable music and video data to be reduced greatly, without a similar perceived loss in quality. The MP3 algorithm is a good example [92].

Illusion and geometrically based magical effects provide a practical real world example of when the human perceptual system can be tricked with carefully presented stimuli. The ability to scientifically examine the extent of the relationship between stimulus and perception is a useful tool for a magician wishing to fully exploit the potential of these types of tricks.

2.2.3 Cognition

2.2.3.1 Perceived risk in magic tricks

A magician may play upon perceived risk, for greater impact of an effect - bullet capture effects, where magicians appear to catch a bullet, fired from a gun, in their mouths, popularised by John Henry Anderson sometime around 1840 [93], rely entirely on the possibility in the minds of the spectators that the trick may go horribly wrong. Without the element of risk (perhaps the magician is replaced by a robot), the impact of the trick would be greatly reduced, if still mysterious. The idea of a trick failing is an inherent part of the thrill of watching a magic trick; indeed, participants will often attempt to subvert or second guess the methods of a trick in order to engineer a failure, only to be rewarded with an even greater pay-off when the trick they have attempted to derail succeeds in its objectives.

Why the thought of a magician failing to capture a bullet in their mouth stands as entertainment, when the trick succeeds, is not obvious, though would appear to be related to the sensation of taking part in risky leisure activities; roller-coasters safely transport their passengers yet feel inherently risky, which increases the thrill of the ride. Surfing *is* inherently risky, but the element of risk is often intentionally increased by the participants in "the pursuit of an ecstatic, transcendent experience" [94]. Viewing others participating in risky activities may provide a similar, vicarious, thrill.

2.2.3.2 Altering memory

How lived experience is remembered is of key relevance to a magician, as they often rely on people recalling certain pieces of information incorrectly, sometimes under suggestion. A well constructed narrative can often reflect on the events of a trick in a way that influences how people recall them. Loftus [95] shows how unreliable eye witness testimony can be, often due to the language used in questioning, or bias and prejudice on behalf of the witness. Simply changing the way a question is phrased can have a significant impact on reported memories.

Roediger [96] describes how false memories may be created, specifically by showing people a list conceptually related words, e.g. 'bed', 'rest', 'awake', etc, relating to 'sleep' ('sleep' is not displayed), and then later asking them to recall the words. Depending on certain initial conditions, length of list and so on, 40% to 50% of subjects recalled the concept word that was never displayed ('sleep'): a memory illusion.

Roediger [97] describes how various cues and instructions as to how an event is recalled can have a significant impact on a subjects' remembrance of scenes and points of interest within these scenes; repeated testing of the memory under certain circumstances can reinforce false information to the point that new false memories are created.

These findings are of obvious interest to a magician who wishes to build a narrative that emphasises certain events, while minimising others, when asking a spectator to recall a trick.

2.2.3.3 Associative thinking

Mentalists very often rely on certain thought processes, including memories, of their spectators, to predict choices or behaviours. Sometimes, during the course of a trick, these predictions may err, though the skilled conjurer will always have an alternative method, or even trick, lined up, should this occur. See Corinda [39], Earle [40], and Anneman [38] for discussions of this performance technique. Mental processes are prone to individuality; spectators thoughts can never be wholly predictable. However, there is a certain commonality to many responses to certain promptings that magicians seek to exploit.

Mental objects - images, sounds, words, concepts, ideas - are often, in the cognitive sciences, termed representations: cognitive symbols, that represent physical realities or cognitive processes that make use of such symbols; see Von Eckardt [98] for detailed analysis. How one representation may give rise to another, for example a visual representation of a cat producing an audible representation of a 'meowing' sound, or the taste of petites madeleines (cakes), for Proust [99], initiating a many-volumed novel's worth of cascading related memories and thoughts, is a complex area of study for philosophers and psychologists. Hartley [100] captures the basic ideas held by the so called Associationist School of thinkers:

> Any sensations A, B, C, etc., by being associated with one another a sufficient number of times, get such a power over the corresponding ideas a, b, c, etc., that any one of the sensations A, when impressed alone, shall be able to excite in the mind b, c, etc., the ideas of the rest. [100]

When magicians search for an as near as possible guaranteed association in the mind of a spectator, they look, knowingly or otherwise, for a particular property of the desired mental representations, as described by Mill [101]: that they are Inseparable:

> Some ideas are by frequency and strength of association so closely combined that they cannot be separated; if one exists, the other exists along with it in spite of whatever effort we make to disjoin them. [101]

In Pavlov's famous experiment, see Shettleworth [102], a dog was conditioned to associate the ringing of a bell with the appearance of food so strongly that an attendant response of salivation was produced on the ringing of the bell in the absence of food.

Implicit association is the idea that some concepts are subconsciously related in human minds - the strength of these automatic associations can be measured using the Implicit Association Test, presented by Greenwald [103]; a series of computer monitor based categorisation tasks, where speed of reaction is correlated to strength of association.

Magic tricks based on these kinds of mental association, that work reliably, can be seen as concrete instantiations of this type of theory of mental activity. Another example of magicians intuitively exploiting something fundamental about the way people, and, it seems, dogs, interact and process the world around them.

2.3 Conclusions

The wide scope of magical techniques, and their rich history, has been made clear. There are many types of trick, and even more individual instances of these types. The main theme that has emerged is that the observation of the scientific principles behind magic tricks appears to offer many possibilities for the imagining of new effects.

2.4 Summary

This chapter summarised the current knowledge related to the origins and forms of magic, and the generation of new tricks, as well as outlining previous work on the scientific study of magic. The next chapter will discuss the knowledge required for using computational methods to generate new magic tricks, and subsequently review the existing techniques available for the evaluation of art and entertainment.

Chapter 3

Literature review: computation, creativity, and the evaluation of creative artefacts

The following chapter continues the investigation of the knowledge that is necessary to generate new magic tricks, using a particular approach, providing detailed sections on various relevant subjects. The topics covered in this chapter are: Artificial Intelligence (AI), computational creativity, and the evaluation of art and entertainment.

3.1 Artificial intelligence and magic

Analysing the various cognitive and perceptual factors at work in the human brain during the viewing of a magic performance, from a scientific perspective, gives rise to the opportunity to create and optimise new magical effects based on these properties. Further, mathematics based tricks are often difficult to generate in an optimal way, for a human, as there may be many different workable configurations of the physical elements of the trick that are difficult to test exhaustively. We see that for any given trick, there will be many parameters, both psychological and physical, for the magician to consider. These parameters may have a range of workable values. The number of ways to combine these various parameters, and their possible values, in search of novel and powerful effects, can often be very large, and thus difficult and time consuming for a human designer to contend with.

Computers, in contrast, are exceptional number crunchers, able to quickly sift through large amounts of data and present it in ways that enables a user to more easily make sense of it. Computers are also very good at searching and optimising parameters to fit certain constraints. They are also useful tools for building models of associations. There are many techniques available to achieve this. As a magic trick design aid, computer software provides a rich set of possibilities.

3.1.1 Search and optimisation

Choosing the right computational technique to suit a given domain is critical to the chances of success. As noted, magic tricks will have many parameters governing their efficacy. Combining these into optimal experiences can be a difficult task for a human, due to the large number of combinations available. Thus, the design of some tricks, or elements thereof, can fundamentally be seen as a search problem. Identifying the correct parameters and analysing how they will impact a given trick is of course key, and for this the scientific study of magic is crucial.

From a computational perspective, the focus of this thesis is therefore on the use of search and optimisation techniques to explore controlled problem domains (parameter spaces) in search of novel and optimal artefacts for use in magic tricks. For this reason, this particular area of AI is concentrated on in this section.

Mitchell [104] explains that search problems fall into three categories: locating targets in a search space (pattern matching), optimising a cost function (optimisation), or path planning. A cost function (or objective function, or fitness function) is a measure of the quality of the solution found by an optimisation algorithm. Solving a search problem, for a computer, entails traversing either physical data stores of some kind, or virtual spaces as defined by a mathematical function.

Search spaces fall into two categories, discrete and continuous. A continuous space might be two co-ordinates, x and y, that describe the position of a point on a plane, where each may vary by any conceivable amount. A discrete version of this space would be represented by the same variables under the constraint that they may be varied by only a fixed amount in each direction, thereby breaking up the searchable space into discrete areas. Various techniques are available to search each type of space. The search spaces that this thesis is concerned with are of the discrete variety, as will be made clear later. Methods for search and optimisation of continuous spaces are mentioned where they are relevant to the general background of the field, or where the method can be applied to each type of space.

In a search space, there may be valid solutions that are not in fact the best possible solution in the entire space; these are local optima. The best possible solutions in the search space are referred to as the global optima. Optimisation is the effort to find parameter values, within a set of constraints, that produce an optimal solution to a particular problem. Some optimisation methods are able to guarantee returning global optima, though may not be able to do so in a practical amount of time, depending on the particular domain.

Combinatorial optimisation problems involve finding an optimal set from another set of objects. The travelling salesman problem (TSP) is a classic in computer science, where a notional salesman must visit each city in a given set, travelling the smallest distance possible. The difficulty is in finding the best order in which to visit the cities. Applegate [105] provides a comprehensive overview of the matter, including descriptions of state of the art techniques to tackle varieties of TSP. A related combinatorial task is the packing problem: fitting objects together into some form of container. Usually the aim is for a single container to be filled as efficiently as possible by a group of objects, or as few containers as possible to pack all the objects. Lodi [106] provides an overview of rectangle packing techniques that provide ways to efficiently place rectangles into constrained geometrical spaces.

Macready and Wolpert [107][108] explain fundamental properties of search and optimisation methods: any given search algorithm will perform better on some problems than others, but over all problems, all search algorithms are indistinguishable. A particular algorithm's exceptional performance on a particular problem will inevitably result in poor performance on another problem: there is no free lunch in search [108]. It follows that there is no free lunch in optimisation. This is a critical observation, as it makes explicit the importance of selecting the right technique for any given domain, and the rejection of any notion that there may be a particular search algorithm that can be optimally applied to any situation.

One of the first optimisation methods developed was gradient descent, explained in detail by Snyman [109]: finding a local optimum of a mathematical function by taking iterative steps in the direction of the gradient of the function at the current point. Gradient descent is also known as the method of steepest descent (or ascent).

Traditional search techniques range from so called brute force strategies, where the entire search space is traversed until a solution is found, to more sophisticated techniques that take into account mathematical properties of the search space and desired solution.

As Russell [110] explains, exhaustive search techniques often define the search space as a tree structure with branching nodes at each level. Various algorithms have been developed to trawl these trees (depth-first, breadth-first, and best-first searches) in search of solutions, which can be highly effective, though suffer when the state space is very large.

Heuristics (simply put, rules of thumb) can be applied to improve search algorithms - the A* algorithm, widely used in path planning, as developed by Hart et al [111], is a good example of this. A* is an informed search algorithm, prioritising the following of paths that appear to offer the best solution. A* keeps track of the total cost of the search as it progresses, whereas a similar so called greedy technique would utilise only the information about the cost of the next step in the search.

3.1.2 Beyond traditional search

Where a traditional technique is not feasible, often due to the size or inherent structure of the state space, more creative techniques are required; Russell [110] provides a clear treatment on the fundamental techniques available. Biological and physical processes provide a rich source of inspiration.

3.1.2.1 Local search

Russell [110] describes local search techniques that operate using a single current node, or state, from which they progress iteratively, usually moving to a neighbouring state at each iteration. Local search techniques are very good at finding fairly good solutions in very large search spaces, and can be configured to run with very little computer memory as they do not hold the entire search space in memory, nor do they generally keep track of where they have previously visited. Local search techniques are also a good choice for optimisation problems that traditional search techniques struggle with. Hill-climbing algorithms, sometimes called greedy local searches, operate by starting at a random node in the search space and iteratively moving to the best available neighbour in the space. This technique is prone to getting stuck at local maxima or minima (where there are no better neighbours to move to from the current state), or plateaux where there are a sequence of neighbouring states of equal quality. Fixed numbers of sideways moves can enable better quality states to be subsequently found, allowing the process to escape from plateaux or local maxima/minima. The number of sideways moves is usually limited to avoid infinite loops in which no better states will ever be found. Restarting a hill-climb search from a different position in the space is also often effective. Xiao and Dunford

[112] describe a relatively recent use of hill climbing techniques to maximise the power output of photovoltaic systems.

3.1.2.2 Simulated annealing (SA)

Hill-climbing is an incomplete algorithm, in the sense that it may never return the global optimum. Because it never makes a move that worsens the quality of the current state, it often gets stuck at local optima, despite the various strategies deployed to improve its function. Simulated annealing (SA) is a probabilistic search technique based on the metallurgical process of annealing [110]. In computing, SA algorithms combine hill climbing and random walks to effectively traverse discrete state spaces in search of optimal solutions. The basic algorithm is the same as that of hill climbing, though instead of taking the best next move available, SA chooses a move at random: if the next state is of higher quality than the current state, it is always moved to; if it is a worse state, then it moves to it with some probability that gradually decreases as the algorithm progresses. This way, the algorithm will sometimes make a *bad* move (more bad moves at the beginning of the search), ensuring, over time, complete coverage of the search space. The rate of decrease of the probability of moving to worse states is called the schedule; if this amount is set low enough SA algorithms return global optima with certainty approaching one.

SA has been applied to problems in many fields. Osman [113] applies SA to flow-shop scheduling; the general problem of how best to schedule a stream of jobs given a certain number of job processing units, minimising idle and waiting times; flow-shop problems are seen in both physical manufacturing environments and computer systems designs. Svergun [114], working in Biophysics, uses an SA procedure to find stable configurations of vectors representing the shape and internal structure of initially chaotically oriented biological macromolecules. Dupanloup [115] show its application to defining the genetic structure of populations by maximising the proportion of total genetic variance due to differences between groups of populations.

SA algorithms can operate as effective design tools, assisting or replacing human designers in certain domains. Wong [116] describes various SA approaches dedicated to VLSI (very-large-scale integration) design - the process of combining many transistors on to single computing chips; a difficult combinatorial problem. Balling [117] created an SA system that designs optimal three dimensional steel frame structures for use in engineering projects by finding the best combinations of standard shapes. D'Amico et al [118] produced a system that tackles the combinatorial problem inherent in the geographical design of police districts, for the better allocation of police resources (mostly cars). Gielen et al [119] used SA to optimise circuit designs, and found the technique to be a flexible and reliable design and exploration tool.

3.1.2.3 Genetic algorithms (GA)

Genetic Algorithms (GAs), initiated by Holland [120], fall within a larger group of so called evolutionary methods (genetic programming, evolution strategy, neuroevolution to name a few). The basic idea of all evolutionary methods is fundamentally the same: to evolve solutions to problems. There is an obvious relationship to this approach with local search methods that iteratively move from one state to another until a solution is found. GAs move from one state to another by combining two states, in a fashion modelled on sexual reproduction.

As explained in depth by Goldberg [121] and Fogel [122], a GA system encodes a candidate solution to a search or optimisation problem as a string of some kind. This encoded version is analogous to a chromosome: the genotype. The phenotype, the instantiation of the genotype, is the candidate solution itself. Many types of encodings are available to GA systems; binary encoding, a sequence of ones and zeros, is often used. The initial population of a GA is a set of randomly generated candidate solutions, each with their own string encoding. An iterative process then takes place, during which all candidate solutions are evaluated according to the designed fitness function (the quality of each candidate solution). Based on fitness, some of the strings are then randomly mutated (mutation) and recombined with one another (crossover), to form new genotypes that make up a new generation. This iterative process continues either for a pre-determined number of iterations, or until a certain fitness is achieved.

Many criticisms have been made about the strengths and weaknesses of GAs, and there is much debate about which components of the technique are critical: mutation of the encodings, or their recombination with one another. In fact, sometimes GAs converge to an arbitrary solution. Goldberg [121] describes various methods to overcome this weakness: using different fitness functions, or imposing certain penalties on certain GA states.

Multi-objective optimisation is a sub category of problems where many goals need to be simultaneously sought by an algorithm. Deb [123] presents NSGA-II, a genetic algorithm formulated to solve these types of problems. Multi-objective optimisation techniques are applied to problems where conflicting constraints mean there is not necessarily a single solution where each objective is optimal; a balance must be struck. Where fitness functions contain conflicting constraints, there can be any number of groups of so called optimal (non-dominated) candidate solutions, termed Pareto fronts (after the Italian economist Vilfredo Pareto, who introduced the concept in the 19th century). At any point in the optimisation process a non-dominated solution is a solution where none of the component fitness values can be improved without diminishing some of the other values. The NSGA-II algorithm introduces the crowded-comparison operator, used as a metric to compare candidate solutions to each other based on the rank of each solution and the density of other nearby solutions.

As with SA techniques, the use of GAs as a design tool has been investigated by a number of researchers. Louis [124] initiated the use of GAs for the design of combinational electronics circuits with his work on structure design. Miller [125] describes using GAs as a type of discovery engine to throw light on unconventional circuit design principles. Arslan [126] describes the structural synthesis of VLSI circuits using GAs. Coello [127] presents a GA automated process to minimise the number of gates used by a circuit. Panduro et al [128] deployed a NSGA-II algorithm to design linear antenna arrays, balancing conflicting constraints of main beam width and side lobe level. These applications point the way for similarly well described yet combinatorially difficult design problems to be addressed in a similar fashion.

3.1.2.4 Constraint satisfaction problems

Constraint satisfaction is the process of finding values for a set of variables that meet certain conditions. For the right problem, constraint satisfaction is a highly efficient method for finding a solution, as the search space can be dramatically reduced due to constraints on the variables closing off large areas of potential, but not correct, solutions. There are various algorithms that may be used, including forms of backtracking and local search (Russell provides an overview [110]).

For example, the simplex algorithm, used in linear programming, a method for solving constraint satisfaction problems, was introduced by Dantzig in 1947 [129], who described a set of techniques he developed to solve logistical problems (scheduling, *programming*) faced by the US military.

3.1.2.5 Neural networks

A neural network is a biologically inspired computation system, introduced by McCulloch and Pitts [130] in 1943; it is a form of learning by a computer inspired by the workings of the human brain. Perceptrons, computational models of neurons, can be trained on data sets to respond in certain ways, and subsequently used for pattern recognition (a form of search). Chu [131] explains that a neural network can be viewed, once trained, as a rapid state space transformation machine; under the right conditions, a very efficient search mechanism. The kind of optimisation of a function that a neural network performs is often based on gradient descent methods; during the learning phase the neural network optimises its parameters to suit the input data given.

3.1.2.6 Swarm intelligence

Beni and Wang [132] introduced Swarm intelligence, describing a system composed of many simple agents interacting with each other while reacting to their environment. In nature, swarms of seemingly simple organisms conspire to produce extremely complex behaviour capable of efficiently solving many problems.

3.1.2.7 Ant colony optimisation (ACO)

Dorigo [133] first described ant colony optimisation (ACO), a computational technique based on the way ant colonies are able to optimise their environment. Ants optimally locate sources of food using the least amount of energy. Typically, during these processes, each ant wanders randomly until they locate food. The ant then returns to the colony, leaving a pheromone trail behind it. Meanwhile, all the other ants perform the same task. Should any ant encounter another's pheromone trail, it will halt its random walk, and instead follow the trail to the food source, before returning to the colony, thereby strengthening the trail further. In this way, food sources will be maximally exploited, and once depleted ignored by the colony (pheromone trails are prone to evaporation). Shorter pheromone trails are preferred. Thus, a complex problem, far too difficult to be solved by any single ant, is solved.

Dorigo has used an ACO to find near optimal solutions to the aforementioned travelling salesman problem [134]. Shmygelska [135] has successfully applied an ACO to fold protein structures. ACOs are able to react to dynamic environments; as food appears and disappears, the ant colony automatically adjusts to the change. Rahman [136] explains how this observation can be beneficially used in evacuation planning in dynamic built environments. Zanjani [137] describes an ACO for packet routing in ad-hoc wireless networks, as used by the military.

3.1.2.8 Particle swarm optimisation (PSO)

Particle swarm optimisation (PSO) is a useful technique for performing optimisation where the gradient of the problem is not known. PSO algorithms can be applied to continuous state spaces. Reynolds' Boids [138] lay the foundations for this type of algorithm, providing a way to produce realistic flocking behaviours, mimicking flocks of birds and schools of fish without the use of pre-determined movement scripts. Boids are essentially a modification Reeves' [139] work on modelling smoke, or sprays of water - each particle in the system is programmed to have its own behaviour; the appearance of clouds of smoke or sprays of water emerges naturally from the interacting behaviours of each particle in the system. Subsequently, PSO was introduced by Kennedy, Eberhart and Shi [140]; initially, the technique was designed to simulate social behaviour. After careful analysis and modification, it was seen to be performing optimisation. PSO relies on particles operating as candidate solutions at randomly generated points in a search space, moving at a variable velocity as better solutions are found; each particle follows its nearest best candidate solution; the best solution and state of each particle is iteratively updated.

3.1.2.9 Stochastic Diffusion Search (SDS)

Bishop [141] introduced Stochastic Diffusion Search (SDS), that falls broadly within the swarm intelligence field. SDS processes can be shown, given the right circumstances, to converge to a global optimum. SDS processes derive much of their computing power from the partial evaluation of an objective function (making only a subset of the calculations needed to fully evaluate a candidate solution). The communication processes that drive them are also critical.

During SDS, a population of agents will iteratively examine the search space, communicating with each other about promising zones. Each agent holds its own hypothesis of a solution, which it partially evaluates against the search data during each iteration, and if promising, under certain conditions, will be communicated to other agents. SDS processes halt when sufficiently large stable clusters of agents form around a particular hypothesis. For smaller problems, this type of algorithm is of negligible benefit; however, for problems where evaluating the objective function fully is costly, SDS can provide large computational benefits.

SDS has been applied in a number of fields. Williams and Bishop [142] show how it can be used for the estimation of hyperplanes in many dimensions (useful for image analysis), comparing favourably with the standard techniques for this task (RANSAC [143]). Grech-Cini [144] has used SDS processes to locate facial features in images. Hurley and Whitaker [145] describe an SDS system that optimally selects sites for wireless transmission networks, maximising coverage, even for large problem sets. Evans and Ferryman [146] applied SDS as an object locator and tracker in visual scenes. Hernandez-Carrascal et al [147] used SDS for feature tracking, a key step in the derivation of Atmospheric Motion Vectors (used in weather prediction systems).

3.1.3 Reflections on search and optimisation

The field of search and optimisation is wide, and very active. The majority of the most commonly used techniques have been reviewed, and shown to be useful in various application fields. There is constant ongoing work to tune and tweak the various parameters that control the efficacy of the various algorithms, sometimes resulting in small breakthroughs in performance. The key issue for this thesis is that there are different techniques available, and that they are all good at different kinds of problems. Sometimes, hybrid systems may be used. Often, the difference in performance between one variant or another of a particular algorithm may be rather small in a practical sense, but the performance of two different categories of algorithm (perhaps GAs and PSOs) may be large. The key point is that choosing an appropriate category of algorithm will allow the performance of a task that would be impractical for a human to undertake.

As we will see in later chapters, some techniques are more suitable for use in optimising magic tricks than others, though the flexible nature of the framework under discussion allows for the use of any technique should the need arise. Of interest here are those techniques that are particularly useful for dealing with combinatorial problems whose state space makes the use of exhaustive search techniques impractical. Magic trick design that involves the combination and recombination of physical elements that make up a whole, be they pieces of a jigsaw or playing cards, is an example of this type of problem - the more elements that are required for the creation of the trick, the larger the state space. Evolutionary algorithms, such as GAs, are known to be useful for this type of problem, though do suffer from various issues that must be taken into account when being applied: notably, the possibility that the algorithm will converge to an arbitrary solution. One advantage of GAs is that the fitness functions used can encapsulate the idea of the overall quality of a trick, enabling the differentiation of various potential solutions.

Simulated Annealing is another excellent candidate technique that can be deployed to solve difficult combinatorial problems. A major advantage of simulated annealing, in the context of magic trick design, is that it can be configured to search for a good approximation to some ideal solution in very large search spaces - for a magic trick designer facing a discrete combinatorial problem, such as ordering a deck of fifty two playing cards a certain way, this provides a way to find a viable solution where previously none was available, with some degree of confidence as to its quality.

Traditional search techniques are, in the context of the type of problems encountered in the work presented here, often found lacking - they take too long to search the problem space, providing no feasible solutions in a reasonable time. While they may guarantee the eventual finding of a globally optimal solution, this may take centuries, if not millennia, of computation time.

Of the other techniques discussed, perhaps of most potential use to the magic trick design process is SDS - in certain circumstances it may prove the most effective technique. Critically, the objective function must be decomposable; i.e., able to be evaluated partially. While SDS has not been deployed for any of the work presented here, it should be considered a potentially very beneficial tool for a computationally based magic trick designer, as it is able to provide globally optimal solutions to large state space combinatorial problems.

3.1.4 Computational creativity

Given the above observations on how computers may be configured in sophisticated ways to solve certain problems, or to optimise given parameters, it is understandable that, since their inception, they have been the subject of speculation as to their abilities to take over creative work that human beings excel at; for example: music, painting, stories, poetry, and comedy. Computational creativity is the field that addresses the challenge of building creative computational systems.

From the very beginnings of computing, the idea of machines being designated as creative entities in their own right has been treated with some scepticism: Ada Lovelace, described as the world's first computer programmer, due to her work detailing uses of Charles Babbage's Analytical Engine [148] (the first general purpose computing machine, never built) understood that this new machine would be capable of creating new works of music of any degree of complexity, but she also believed that the attribution of credit as to the work's creation must lie with the engineer that configures the machine, not the machine itself:

> The Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform. It can follow analysis; but it has no power of anticipating any analytical relations or truths. [149]

Alan Turing, the originator of the modern general purpose computer, and deep thinker on the topic of the possibility of machine intelligence, disagreed with Lovelace on this matter:

> A variant of Lady Lovelace's objection states that a machine can 'never do anything really new.' This may be parried for a moment with the saw, 'There is nothing new under the sun.' Who can be certain that 'original work' that he has done was not simply the growth of the seed planted in him by teaching, or the effect of following well-known general principles. [150]

Understanding what it means to perform a creative act is a difficult problem. Boden [151] supplies a neat summary of what lies at the source of creative thinking:

> Creativity is not a special 'faculty', nor a psychological property confined to a tiny elite. Rather, it is a feature of human intelligence in general. It is grounded in everyday capacities such as the association of ideas, reminding, perception, analogical thinking, searching a structured problem-space, and reflective self-criticism.

Following work by Newell and Simon [152], Boden identifies the criteria that the output of creative systems, human or computational, must be *novel* (to the system itself) and *useful* (evaluated as such). Boden [151] describes three different type of creativity that humans, or computer systems, may engage in:

1. Combinational - the novel combination of two or more familiar ideas.
2. Exploratory - the generation of novel ideas by the exploration of structured conceptual spaces.
3. Transformational - the transformation of one or more dimensions of a structured conceptual space, enabling the acquisition of previously unavailable new ideas.

Interestingly, although transformational creativity is the most radical of the three, and likely to result in the most unexpected new ideas, it is in fact exploratory creativity that the majority of creative people are engaged in, as Boden [151] describes:

> Many human beings - including (for example) most professional scientists,

> artists, and jazz-musicians - make a justly respected living out of exploratory creativity. That is, they inherit an accepted style of thinking from their culture, and then search it, and perhaps superficially tweak it, to explore its contents, boundaries, and potential.

There has been an effort by Wiggins [153] [154] to formalise Boden's notions of creativity in to a computational framework, noting the similarities between exploratory creativity and many computational search methods, in order to better explore the conceptual underpinnings and try to lay out a way forward that could encompass the automation of creative acts. Colton et al [155] build on these ideas and present a computational creativity theory that contains both a descriptive model of creative acts (that they term FACE), and a descriptive model of the impact that computationally creative acts may have (termed IDEA).

Colton and Wiggins [156] summarise seminal works in the field of computational creativity, and provide a brief history of the topic, along with a working definition of what it is:

> The philosophy, science and engineering of computational systems which, by taking on particular responsibilities, exhibit behaviours that unbiased observers would deem to be creative.

They contrast such systems with those produced in the HCI (human-computer interaction) field [157], that assist human beings to generate creative work; for example Photoshop (visual art), Max/MSP (new media), AutoCAD (engineering/architectural/product design), Cubase (music), Eclipse (software development) etc. The main difference, they argue, is that computationally creative systems take on responsibilities for the creation of artefacts that HCI systems generally do not. They also introduce the idea of an unbiased assessor to fairly evaluate the outputs of computationally creative systems. They note the readiness with which human beings attribute creativity to the programmer and not the machine. Interestingly, they see computational creativity as moving away from a problem solving paradigm, the most common approach in the wider AI field (and to a large extent their own and others computationally creative systems), towards:

> ...an *artefact generation* paradigm, where the automation of an intelligent task is seen as an opportunity to produce something of cultural value. [156]

Creative computational systems have been implemented in many fields. A detailed history is given by Cardoso et al [158]. The systems developed in each area are often radically different to one another in the approach they take to generating novel and useful outputs, using different kinds of data structures, and applying different algorithms to the problems at hand, tailoring each to the specific conceptual space. An exhaustive list and description of each is implausible, however there are some systems of note in the various fields.

3.1.4.1 Language, stories, and poetry

Generating poetry, perhaps the most nebulous and specifically human of all the arts, has also been subjected to a computational approach. Natural language is very difficult terrain for a computer. Gervás developed a system, ASPERA, to compose formal Spanish poetry [159]. Diaz et al [160] created a similar system, COLIBRI. These expert systems (a system that relies heavily on the formalisation of knowledge from domain experts) use case based reasoning (the generation of solutions to problems based on known solutions to similar problems) to generate poetic versions of inputted text by querying a database of previously written poems. Oliveira [161] provides a more comprehensive overview of the various approaches to automatic poetry generation.

Sardonicus, developed by Veale and Hao [162], is also a case based system; it constructs a database of similes for adjectives from data on the internet, which is then used by a system named Aristotle to suggest new metaphors for provided descriptive goals.

The MINSTREL system, developed by Turner [163], generates short stories of reasonable quality (given their origin); the system is based on the idea of separating out, and formalising, the goals of the characters in a story from the narrative goals of the author. An intelligent search procedure is performed on a database of known previous answers to the problems that meeting these goals throws up, resulting in novel stories.

3.1.4.2 Comedy

Humour is often attempted via computers: the JAPE (Joke Analysis and Production Engine) system, from Binsted [164], was an early successful development, capable of generating puns that young children found humorous by analysing and formalising the structure of certain types of jokes and finding a way to score new candidate jokes for meaning and humour. The JAPE system is also interesting because the authors used empirical methods to evaluate the quality of the creative artefacts that it produced; the jokes it produced were consistently rated, by children, on a par with human created jokes of a similar kind.

3.1.4.3 Music

Generating music is a challenging task for computers, and a rich vein of research in computational creativity. Cope's [165] EMI (Experiments in Musical Intelligence) software produces musical scores in the style of existing composers. Cope argues strongly in favour of the notion that computers can be considered creative; those that disagree with this position are thought by him to have defined creativity itself so narrowly that the term could not be attributed even to humans. Cope's own definition of creativity differs from the previously discussed attributes of novelty and usefulness [151], preferring: "initialization of connections between two or more multifaceted things, ideas or phenomena hitherto not otherwise considered actively connected". Cope's work is controversial, and has attracted criticism, notably from Wiggins [166], for not being clear on its methods of musical creation, lacking basic scientific rigour, and producing poor quality music.

Horner and Goldberg [167], McIntyre [168], Papadopoulos and Wiggins [169], and Phon-Amnuaisuk et al [170] have all used a GA as the core process in a software system engineered to compose music. These systems all computationally evaluate the quality (or, in GA terms, the fitness) of the outputs during the iterative process of creation. Similar approaches that instead use a human assessor, known as Interactive GAs (IGAs), have also been developed by, among others, Horowitz [171], Ralley [172], and Biles [173]. The main limitation of this interactive approach is that a human must assess the outputs of the system at each stage of the evolutionary process, which is inefficient. Spector and Alpern [174] used Genetic Programming (GP; the programming code itself is evolved) methods for the creation of musical phrases intended to respond to other phrases in jazz music. Johanson and Poli [175] created GP-Music, another GP system, that also uses automatic fitness (quality) assessors. Iliopoulos et al [176] describe an evolutionary system capable of generating musical motifs in polyphonic passages (more than one note at any given time) to order. Chuan and Chew's [177] hybrid system focusses on creating accompaniments in a specific style.

The idea of building computer systems that first learn a model of a particular conceptual space, for example music, and then having them alter the model to generate new artefacts, is the subject of a large theoretical effort by Wiggins [178], whose work relies on Baars' Global Workspace Theory [179] as a conceptual framework, the statistical modelling of musical perception pioneered by Pearce [180], and ideas from Shannon's Information Theory [181].

3.1.4.4 Visual art

Perhaps the most successful and controversial creative system developed is the Painting Fool from Colton [182], an AI project with the aim of one day being taken seriously as an autonomously creative visual artist. The Painting Fool is a hybrid system, using various techniques to automatically generate the elements of a picture. The project also investigates the sociological implications of the idea of computational artists, and the impact the created artefacts have with the general public.

Monmarché et al [183] describe the application of an interactive GA to ant colony paintings, whereby the rules of movement and colour for each ant are parameters for the GA to evolve. Greenfield [184] describes a system based on these ideas, but dispenses with the interactive part of the GA, substituting fitness functions intended to guide the ants to progressively more aesthetically pleasing outputs (for humans).

Al-Rifaie [185] describes a hybrid PSO and SDS system that sketches drawings from an inputted image. SDS has also been explored in the context of computational creativity by al-Rifaie and Bishop [186], who discuss PSO techniques and their potential in this capacity, and explore the notions of weak and strong computational creativity.

3.1.5 Reflections on computational creativity

Whatever the outcome of the philosophical debates about the nature of creativity, one thing is certain: computers are useful tools in creative endeavours. In terms of computational creativity, the focus of this thesis is in the exploratory creativity domain; using computers to take responsibility for searching controlled problem domains for new solutions (magic tricks), or optimal versions of existing solutions. There is also a focus on the use of computational techniques as creative aids, in the HCI tradition, and how these tools can be gradually augmented with more intelligent features. The difficult philosophical questions of whether this constitutes the design, implementation, and application of a genuinely creative computational entity are left unanswered.

3.2 Assessment and evaluation of creative artefacts

Measuring the success or otherwise of art and entertainment is difficult. Measuring phenomenological experiences such as those experienced during magic tricks is also difficult. For a creative system, computational or human, there are two kinds of assessments that are made of artefacts generated for human consumption; those the system makes itself during the creative process, and those made of an artefact by an audience. During the creative process, unless interactive methods are used, in which a human stands in as the assessor of the proposed artefacts produced by computational systems, it is necessary for these systems to have some way of assessing the aesthetic, or entertainment, value of their intermediate outputs.

Galanter [187] provides a detailed overview of the issues and difficulties involved in computers evaluating their own creative outputs. A basic notion, from Galanter:

> In practice artists will execute countless micro-evaluations as part of making aesthetic decisions for works-in-progress. Once completed, artists evaluate the final product, gaining new insights for the making of the next piece. If computers are to become artistically creative their need for an evaluative function will be no less acute. Computer artists have invented a great variety of fecund computational methods for generating aesthetic possibilities and variations. But computational methods for making aesthetically sound choices among them have lagged far behind.

This type of evaluation is the kind implicitly built into the fitness functions in GAs used in computationally creative systems, or related measures for other techniques; usually, the rules of assessment are built in by the engineer, even if the computer system performs the many evaluations needed. Once determined, the algorithm proceeds with its built in measure of what will be aesthetically pleasing. The computer system does not build its own aesthetic framework from the ground up, it will usually have human notions of aesthetics handed to it in a de-constructed form.

Some of the judgements that need to be made, during the creative process, when considering the potential impact of magic tricks are somewhat different, and arguably inherently more measurable than those in other fields, such as visual art, as they are less subjective. For example, it is easier to explicitly measure whether an event exhibits a certain perceptual feature, for example visibility, than it is to measure the artistic value a painting is likely to hold for people. The painting may mean something deeply personal to one person, and absolutely nothing to another, in a way that would be difficult for a computer to model. Visibility, on the other hand, may be more reliably predicted.

When people are presented with a completed computer generated artefact, they will evaluate it in much the same way that they evaluate a human generated artefact - if, that is, they are unaware of the creator's identity. There has been some interesting work done investigating the thorny issues around assessing the creative impact of computational artists and their artefacts, notably by Colton and Ferrer [188], who report on an exhibition at which a dialogue took place between a researcher presenting artwork generated by software, and a classically trained artist taking inspiration from the computational processes. The exhibition placed computer generated artefacts in an art production and art historical context, and explored ideas such as *loss of aura* and *creative responsibility.* The loss of aura issue refers to the idea that once it is known by an audience that a particular piece of work is not human created, it can lose a certain phenomenological property that can be quite disturbing. Colton is making efforts to replace this human created aura with a similar machine created aura.

Understanding how to measure the overall success of an artefact consumed by real people, particularly magic tricks, is thorny. However, in fields focussed on entertaining an audience, such as certain genres of film, novels, comic books, and computer gaming, a grasp of how much the audience has *enjoyed* the artefact goes a long way to summarising its success.

3.2.1 Enjoyment

There is scarce literature available on the measurement of enjoyment of magic tricks, though Marshall [189] conducted simple questionnaires to gauge an audience's basic reactions. Instead, magic may be viewed as belonging to the wider areas of art and entertainment, and media in general. For computational systems that produce artefacts in these fields, that are intended for human consumption, there needs to be some way of evaluating the final outputs. As mentioned, assessing art, visual or otherwise, *aesthetically*, is a notoriously subjective endeavour. Assessing *enjoyment* of art and entertainment, in a more concrete way, may be achieved more directly. However, as Nabi and Krcmar [190], writing from the field of communication research, warn:

> The notion of enjoyment seems, on its face, so clear, so obvious that it appears to need no further explanation.

Further, Raney [191] notes:

> Much like entertainment, scholars have yet to conclusively define enjoyment.

Csikszentmihalyi [192] introduced the idea of flow (optimal experience) being the fundamental state while an activity is being enjoyed. The type of activity he researched was wide ranging, and not limited to the consumption of entertainment, but rather more engaged activities such as composing music or playing chess. The basic idea is that flow is the state achieved when performing a task that is highly engaging yet effortless, alters one's sense of time, can be completed and has clear goals, and takes the participant out of themselves and their current reality in some way.

Assessing enjoyment of entertainment is often achieved with a single measure, where the participant is simply asked to rate how much they enjoyed a particular event; see Greeson [193], Knobloch and Zillmann [194], and Krcmar and Kean [195] for examples. This approach appears to capture the fundamental piece of information required in many situations.

Nabi and Krcmar [190] introduce a more complex tripartite model of enjoyment that encompasses affect, cognition, and behaviour, that has subsequently been used for the analysis of enjoyment of various types of media. They hope that the measurement of enjoyment by researchers will be undertaken along the three dimensions of their model. They further distinguish between *message* and *experience* related enjoyment; the difference between enjoying, for example, a film (the message) purely on its own merits, and the overall event of going to a cinema to see the film (the experience).

Lin et al [196] developed a scale for measuring the enjoyment of web based media, based on 14 variables grouped into three larger categories: engagement (focussed attention), positive affect, and fulfilment (need or desire).

The study of enjoyment is regularly used as a way to investigate the cause of certain behaviours, on the assumption that enjoyment of media will result in more consumption of similar media. Bryant et al [197], and Gantz and Wenner [198], have investigated the various factors in the enjoyment of sports. Krcmar and Greene [199], and Slater [200], have tried to understand why violent entertainment remains popular. Similarly, the wide scale consumption of horror films by adolescents is analysed in Johnston [201]. The viewing of films that make one sad, yet are still reported as enjoyable, is investigated in Oliver [202]. Valkenburg and Cantor [203] investigate the various likes and dislikes of children for different entertainment, and speculate as to the origin of these tastes.

Ijsselsteijn et al [204] have made steps towards a multi-faceted measurement of the enjoyment of computer games, producing the GEQ (Game Experience Questionnaire) that tries to encapsulate the various factors involved in the experience of overall enjoyment of gaming. They also use psychophysiological recordings (e.g. EEG, facial EMG, EDA) to distinguish various player emotions during enjoyment, and otherwise, of games. Feng et al [205] present a method of evaluating enjoyment in computer game playing based on Nabi and Krcmar's tripartite model, which boils down to a series of questions regarding the way the playing of a particular game makes a participant feel and act, measured on the three scales of affect, cognition and behaviour. GameFlow, introduced by Sweetser [206], is a model, adapted from Csikszentmihalyi's flow ideas, that attempts to predict when a game will become enjoyable for the participant based on eight elements: concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction.

Casares et al [207] investigated various ways of assessing entertainment value when viewing online comics. For their purposes, the most effective method was to use a short post-viewing questionnaire.

Monk et al [208] introduced the the idea of Funology; they argue that work should be undertaken to study what can make the use of software and computer systems enjoyable, rather than merely functional and effortless.

The development of qualitative research methods - a large field in its own right, encompassing a myriad of approaches, described in detail by Patton [209] - can serve to enrich our assessments of people's subjective experiences of an artefact or spectacle, and potentially yield fresh insights. Understanding an experience is not always easily quantifiable, and it can help to have a different, or additional, method of assessment. Sometimes interesting patterns and insights may be gleaned from qualitative data that may simply not be present in quantitative studies.

McCarthy et al [210] performed a qualitative study on the enjoyment of sports, in an attempt to understand the constituent emotional elements of enjoyment of sporting activity. Lin and Gregor [211] performed qualitative studies to investigate how to design websites for learning and enjoyment. Klimmt et al [212] used qualitative methods to understand the factors involved in the enjoyment of web browser based computer games.

There would appear to be a large gap waiting to be filled with research dedicated to understanding the various psychological elements of viewing magic that makes it, specifically, enjoyable.

In the same way that it is critical to select the right search and optimisation technique for a particular problem, it seems that choosing a relevant measurement or assessment method is vital to gain an appropriate understanding of the enjoyment of a given art or entertainment artefact. More complex investigations into the principles and effects of enjoyment require more fully realised models, while often straightforward, even single measure, scales tell a more direct story.

3.3 Conclusions

This review has necessarily covered a lot of ground. This is due to the wide scope of knowledge that is applicable to magic in general, and to the variety of computational methods available as tools for the production of new magic.

The various philosophical implications of introducing computers into a creative context have been explored, along with methods for assessing creative artefacts, both by humans and computers. The main theme that is developed is the complex nature of creativity, the multi-faceted nature of the perception and performance of magic and where, specifically in the field of developing new magic tricks, computational systems may be of benefit.

The scientific study of magic can lead to the unveiling of various parameters that have the potential to be used as constraints and components of cost functions in algorithms that search structured problem domains for novel and optimal artefacts for use in magic. Various methods for the evaluation of the enjoyment of these artefacts have been described, identifying the various simple, and complex, approaches attempted previously in similar fields.

The material covered during the course of this chapter, while encompassing various seemingly disparate topics, provides the foundations on which an implementable computational process to design and evaluate magic tricks can be built. Any computational system that is deployed to output artefacts for consumption by humans needs to be configured in a way that reflects the way that humans perceive and experience such artefacts - various methods to achieve this have been outlined. Without the ability to build these considerations into the cost functions of the algorithms, artefacts that can be considered novel and interesting to humans would be out of reach. In order to find these artefacts, often large state spaces must be traversed, requiring the selection of a suitable specialist computational technique, as discussed. Finally, in order to rigorously evaluate the success, or otherwise, of the design process, a suitable evaluation methodology must be in place - various existing approaches have been outlined.

While there is a lot of ongoing work into the scientific study of magic, and much work on various AI techniques useful in many creative areas, there would appear to be a large gap in extant research into the computational production and assessment of new magic.

3.4 Summary

This chapter summarised the current knowledge in the areas of AI relevant to the potential production of new magic using computational systems, and methods that may be used to evaluate the outputs of such systems. The next chapter will introduce a framework for designing, optimising, and evaluating magic tricks. It will argue that this conceptual framework encapsulates the multi-faceted nature of trick design, and provides an iterative methodology that allows assessment and refinement of a trick, towards a final real world validation.

Chapter 4

A framework for designing, optimising, and evaluating magic tricks

The previous chapter summarised current knowledge regarding magic, the science of magic, computational techniques from the AI field, and evaluation methods for creative artefacts. There is an obvious gap at the conceptual centre of these fields, where they can be combined for the purpose of designing more effective magic tricks. There is an opportunity to build better magic by applying scientific and computational methods in a way that is informed by the rich history of magical effects.

What has been made clear is that there are a number of types of magic trick, each with their own particular properties. Sometimes, these properties are mathematical in nature, or amenable to mathematical modelling.

Designing new tricks is difficult, with many effects being carefully refined over generations of magicians. Given the nature of magic tricks, it is vital to consider the psychological features of a given type of trick.

This consideration can naturally lead to the definition of a problem domain that defines potential workable values of various physical parameters that will result in a desired psychological effect. The parameter set can often be unmanageable for a human to combine and recombine in an optimal way.

Computers make excellent search and optimisation engines, able to assist designers with combinatorial tasks. There is an ongoing philosophical debate about the extent to which this can constitute computational creativity; for practical purposes it is more effective to focus on what the best available computational technique might be for a given problem domain. Sometimes this will be a method from the AI field, other times a more straightforward software tool; in both instances the computer can assist the human designer.

In the real world, magicians are interested in effective tricks. While the efficacy of a new design may be theoretically excellent, and perform well in lab tests, it can be argued that a more concrete test is to sell a working product to a magician (budding, or otherwise).

4.1 The framework

The approach that this thesis takes to combining the described elements is to develop a conceptual framework of optional components, that can be fitted together in a flexible and reliable way, for the creation of new tricks. This allows a designer to start work by generating ideas for the type of trick they would like to achieve, and then apply aspects of the framework methodically, to assist in the creative process. This chapter presents the general framework and process that has been developed, detailing each component and how it fits together with each of the others.

4.1.1 Background

There is precedent for applying a framework that synthesises psychological phenomena with computational techniques to produce output for entertainment purposes. For example, Lian et al [213] show a computational framework, script-to-movie (S2M), that attempts to generate new video content from existing videos married to user supplied scripts. Their approach views this task as a constrained optimisation problem that blends syntactic visual content with semantic story plots. They use both quantitative and qualitative evaluation methods.

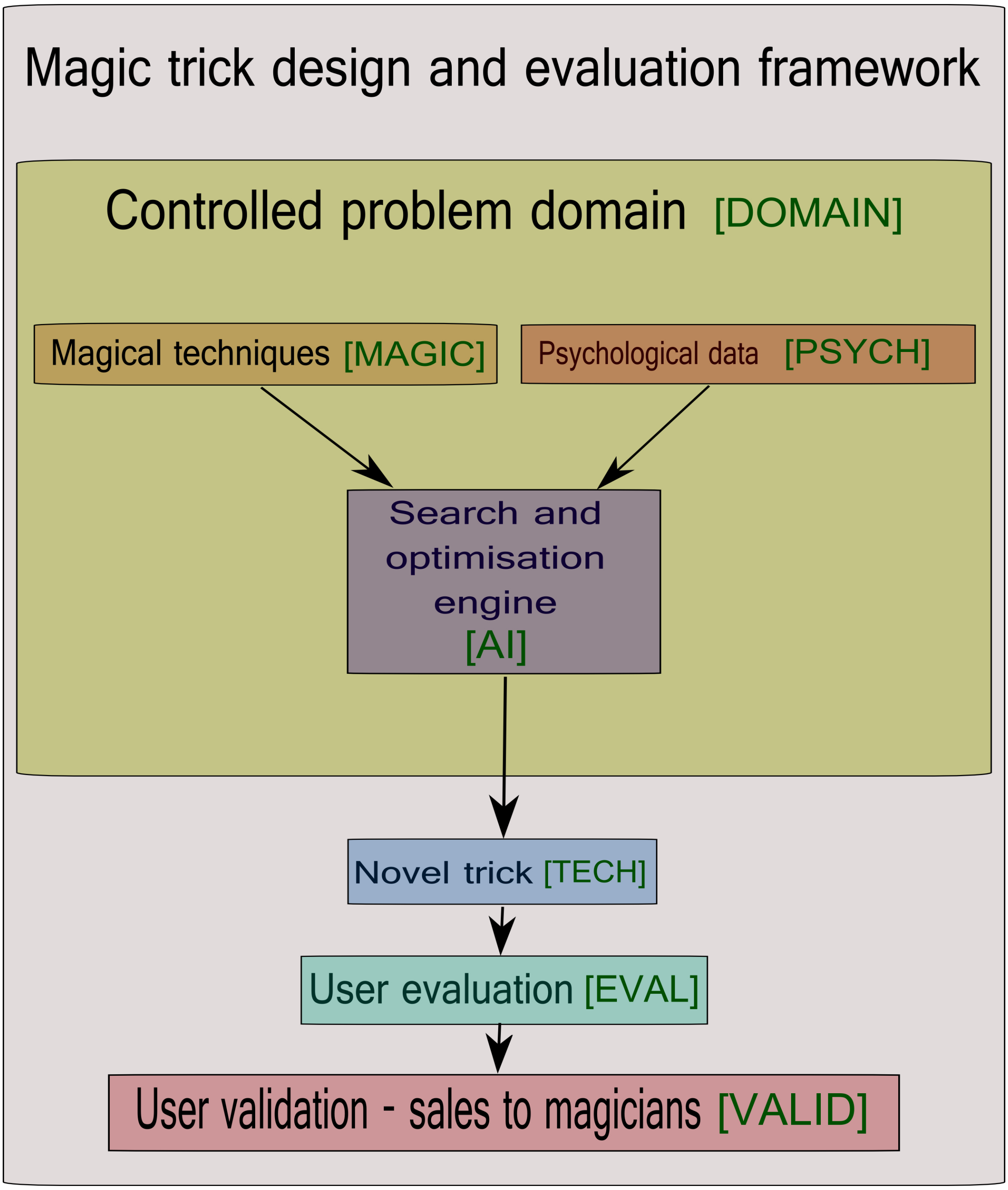
Marshall [189] presents a framework for synthesising computational methods with performance theory into a framework for creating illusions in performance. This work also takes ideas from magic theory on deception and misdirection. The framework contains an evaluation component.

4.1.2 Optimisation

Fundamental to the framework presented here is the idea of optimisation. The framework is set in the context of an iterative process of design and test. During each phase, elements of a proposed magic trick are analysed, and considered as candidates for optimisation.

See figure 4.1 on page 68 for a diagram that shows the overall structure, and how each of the components detailed below sits within this context.

Figure 4.1 The magic trick design and evaluation framework.



4.2 Framework components

The components, and how they interact, are presented and explained below. Each component is given a capitalised name for reference throughout the rest of the thesis.

4.2.1 The trick [MAGIC]

In most circumstances a new trick will be based on existing tricks. Very rarely, an entirely new category of trick is invented. During the application of this component of the framework a new trick, or a new version of an existing trick, is described. Part of the work that is undertaken during this phase of the framework is a consultation with domain experts (magicians and trick designers) relevant to the trick design. This knowledge can be readily found in the existing literature, as we have seen in chapter 2. A lot of expert knowledge is also held in the heads of the experts themselves, thus discussions about various factors can be of great benefit. Talking through an idea can often illuminate previously hidden areas that need to be considered; for example, the presentation of a trick may be flawed from a narrative perspective, or easily improved in some small mechanical way. The more opinions that can be gleaned the better. The main task to complete for this component of the framework is to gather as much relevant knowledge about a proposed new, or existing, trick as possible, and to clearly define the operation of the trick.

The knowledge gathered needs to be understood in terms of the factors that may be systematised, and those that are more nuanced performance issues. Often, a desired effect will be the starting point. To illustrate how each part of the framework may be deployed, an example effect is now described (this is an imaginary effect only, not implemented), that will then be the subject of the discussions in each of the coming sections:

- The performer takes a deck of cards from their pocket, and shuffles it in front of a spectator.

- The performer fans out the cards, face down, for the spectator.
- The spectator selects a card, and takes it from the deck.
- The performer takes a card from their pocket that is an exact replica of the spectator's card.

The challenge then is to work out a method to produce this effect. As detailed in chapter 2, there are many methods to choose from, used by domain experts in related tricks, some of which may be found in books (e.g. false shuffling), others only in the repertoire of certain magicians (perhaps a particular way of forcing a card choice).

This stage of the process requires careful research to gather information from the domain experts about the range of possibilities available to successfully implement each element of the effect. Once the research is completed, the trick designer has a good overall view of the trick, and has selected methods to solve each of the design problems presented by the desired effect. A prototype version is produced, that may in fact not be magical in practice. For example, the chosen methods (again, for illustration), may be:

- The deck of cards are marked in some way. Each card has a marking on its back that uniquely identifies the card. The magician reads this code off the back of the spectator's chosen card.
- The markings are very subtle, and only visible when enough ambient light is present, and will only be visible if they are looked for.
- The deck will be initially ordered in a certain way that looks random on casual inspection.
- The magician will perform a series of false shuffles that either do not alter the order of the cards, or only reorder sections, so that groups of cards remain together.

- The performer will force the spectator to choose a card from a particular section of the deck.
- The performer will keep a replica of each of the cards in the forced section about their person, in various pockets.

This prototype of the trick method would solve all the design issues inherent in producing a magical effect of this kind. However, it leaves a number of unanswered questions about how the trick may be most successfully constructed.

4.2.2 Psychological observations [PSYCH]

There may be psychological observations to take into account. Some elements will be relevant only to the performer; for example, remembering which pocket each of the hidden cards are in. Mostly, the performer and the spectator will be implicated; for example, when shuffling the cards, the performer must have mastered the manual dexterity skills necessary for the spectator to perceive the shuffles as really mixing up the cards.

Table 4-A on page 72 outlines the various factors and parameters that may be identified for the example trick.

Some of the parameter values for these psychological factors may be unknown, and need determining experimentally. For example, the amount of ambient light present will influence how visible the markings on the card are; the optimal amount would allow the magician to see the markings, while making it harder for the spectator.

Similarly, the shuffling and forcing techniques could be subject to experiments with real magicians to determine the best applicable technique for the widest range of magicians - what is the most effective false shuffle that is easily mastered by the majority of magicians?

The basic story of the trick should also be considered; do any aspects of the trick

Psychological factor	**Relevance**	**Parameters**
The perceptual characteristics of the markings on the cards.	Spectator and performer.	1. The shapes of the markings and their surrounding visual context. 2. The amount of ambient light.
The cognitive characteristics of the ordered deck.	Spectator and performer.	1. The specific ordering of the deck affects the perceived randomness of the distribution of cards.
Does a particular false shuffle technique result in the illusion that the cards have been genuinely mixed?	Spectator and performer.	1. The type of false shuffle deployed. 2. The skill level of the magician.
Will the force go undetected by the spectator?	Spectator and performer.	1. The type of force used. 2. The skill level of the magician.
How easily memorable the pocketed cards are.	Performer.	1. The number of cards in the group. 2. The mnemonic system used to recall the cards.

Table 4-A: Psychological factors for the example card trick.

require justification to the spectator beyond the premise of simply being a trick to take part in? For example, the setup for this proposed effect could be that the magician states at the beginning that they have a card in their pocket, and believes that the spectator has special powers that would enable them to select that very card from a shuffled deck. This is a relatively weak justification for pulling out the card at the end of the trick, and stronger psychological justifications could be worked on. These types of observations are the kinds of narrative tools that experienced magicians are particularly good at developing.

At the end of this stage of the development process, the trick takes a more concrete shape. The various parameters determining the trick's efficacy are known, even if their eventual values are undetermined. Some idea of which parts of the trick should be designed by a human will be clear (often, the narrative). The next step will be to find ways to design the best possible version of the trick.

4.2.3 Controlled problem domain [DOMAIN]

Once the proposed trick has been researched and prototyped, and its psychological factors analysed, it is broken up into discrete parts that can be assessed in terms of how best they can be optimised.

Performing this analysis naturally highlights areas where a computer can be useful. It is often the case that a computer is simply not the best method for solving a particular problem; human brains are extremely sophisticated, and their performance on various tasks far outstrips computational machines. For example, writing a script for a magical performance is usually best left to a human (for now); talented writers are able to produce narratives that contain the right balance of suspense, humour, pacing, and impact. For a computer, this is an exceptionally difficult task that is currently out of reach of even the most sophisticated AI story generation systems. As we saw in chapter 3, the best systems available are still struggling to produce simple, novel, story lines that make sense.

Each discrete element is described in terms of its function, its parameters, its relevance (to performer and/or spectator), and its potential for computational design or optimisation (or otherwise). The idea is to tightly define each element of the trick, and what its role is in the context of the overall performance. The particular computational technique needed is not apparent at this stage.

Table 4-B on page 74 outlines the various parameters identified in the analysis process, along with their potential for computational optimisation.

4.2.4 Computational technique [AI]

When the problem domain is clearly defined, some elements can be seen to contain parameters that can take on a large number of values. Finding the optimal values for these parameters may be a combinatorial challenge best suited to a computer, or could

Element	**Function**	**Parameter**	**Relevance**	**Design**
Card markings.	To be invisible to spectator, visible to performer.	1. Shapes of markings and context visuals. 2. The amount of light.	Spectator and performer.	Computer or human.
Ordered deck.	To appear randomly distributed.	1. The ordering.	Spectator.	Computer or human.
False shuffles.	To appear to mix the cards up randomly.	1. The type of shuffle. 2. Skill of magician.	Spectator and performer.	Human.
The force.	To ensure spectator chooses from a particular group of known cards.	1. The type of force. 2. Skill of magician.	Spectator and performer.	Human.
Pocketed cards.	To allow the magician to easily recall where the cards are during performance.	1. The number of cards in the group. 2. The mnemonic system.	Performer.	Computer or human.

Table 4-B: Problem domain parameters for the example card trick.

be such an inefficient task for a human to perform that enlisting the assistance of a computer would save a lot of time. There may be some aspect of the trick design that a computer is able to take responsibility for.

Identifying areas suitable for computational assistance requires knowledge, and imagination, on the part of the designer. A key issue is how a computer is able to evaluate the quality of the solution that a certain set of parameter values represents. Computers may be very good at generating all the possible different combinations, but fare less well with subjective measurements of the resulting solution. In some instances, both the generation of candidate solutions, and their evaluation, may be feasible for a computer to perform. Identified psychological factors may be easily built into an evaluation function. These are the elements that will benefit from computational assistance.

As outlined in chapter 3, there are many algorithmic techniques available, and selecting the correct method to match the required task is critical. There may be sophisticated techniques available that the inexperienced designer is unaware of. In a process similar to the consultation that takes place with magicians, it may be necessary to consult computational experts to determine which of the tasks identified in the problem domain may be subject to algorithmic design and/or optimisation.

The discussed example trick contains a number of elements that could be designed by both a computer or a human. The optimal shuffles and forces to deploy are best determined experimentally using human magicians. The group of cards that the magician will pocket and remember is an interesting case, as it is tied in some way to the ordering of the deck. The designer would not want to select a group of cards that when viewed together stood out among a random distribution of cards - for example, a group of eight picture cards in a row might raise suspicions. The number of cards to use could be determined experimentally with real people tasked with recalling varying numbers of cards. The most memorable cards in a deck could also be determined experimentally; in fact Olson et al [56] provide just such an index that could be used for this purpose. This would leave a remaining problem of selecting the requisite number of cards into an innocuous looking group, maximising the memorability of each card. Another experimental task for human subjects.

This leaves the markings on the backs of the cards, and the amount of ambient light, as factors for optimisation. While a human designer could be a good candidate to come up with a coded visual design for the back of each card, there would appear to be the opportunity for a computer model to be utilised here. It is feasible that a computational model of the backs of each playing card could be formalised, allowing for the composition of different shapes to make up the value markings, along with the regular design. This model could be set up in such a way as to allow the variation of components of the designs (size, colour, brush type, basic shapes, density of visual design, and so on). This would lead to a vast number of different possible designs. If a suitable evaluation function for each design could be implemented (to indicate how well hidden the value markings are amidst the regular patterns on the card, while remaining visible to an observer looking for them), this task would be a good candidate for computational design and optimisation, as the computer could search through the designs, gradually altering and honing them to maximise the desired effect.

Further, an ambient lighting model could be implemented as a separate parameter to vary. Tasks such as this are not straightforward for computers to model, though neither are they impossible. While a human designer may be able to come up with a good design that works under certain lighting conditions, it is feasible that a computer could do better.

4.2.5 Technology [TECH]

Props and gimmicks are extensively used in magic tricks, as we saw in chapter 2. This type of technology can solve a range of problems for a trick designer. For a spectator, technology must be a natural part of the narrative of a trick; for example, a magic wand that apparently performs miracles, but actually contains silk handkerchiefs. The need, or opportunity, to use technology in a trick should be clear from the analysis performed with the domain experts, and may sometimes lead to further psychological observations that must be taken into account. Further, the technology design process may naturally lend itself to computational optimisation or assistance. CAD software is an essential tool for stage magic designers wishing to build complex props [23], allowing for rapid prototypes to be modelled before any physical construction takes place.

If the trick being designed is not inherently prop based, then, ideally, technology of this type will be used only where strictly necessary, or where it can be shown to enhance the effect. Empirical work can be done to determine if a piece of technology adds to or detracts from the magical effect experienced by a spectator.

There is a key question around whether computational devices will be accepted by audiences as valid elements in a trick. Audiences are now generally sophisticated enough to understand that mobile phones and other similar devices are capable of performing procedural tasks, and storing a lot of information. This could lead them to dismiss tricks presented by devices known to be capable of these kinds of operations as simply some computational process that, while not fully understood, is not seen as magical. The framework provides evaluation methods that enable a trick designer to test the possibility of integrating active technological devices into effects.

4.2.6 Evaluation [EVAL]

There are two evaluations that the framework needs the capability to make. During the design and optimisation phase, any algorithm used will need to assess the quality of intermediate solutions as it searches for optimal versions. The nature of these evaluations will have been defined during the problem domain and computational technique phases.

Once all the elements of a trick are put together into the final design, combining the human designer's work with any computational artefacts, the final product, the whole trick, needs to be evaluated by performing it for real people. Once these assessments are made, there may be scope for improvements, which can be fed back to earlier phases of the process. This iterative approach allows the trick as a whole to be gradually optimised by careful honing of each element during each iteration. Things that work remain part of the design, while aspects that cause problems are pruned or improved.

4.2.6.1 Developing an evaluation method

As we saw in chapter 3, there are many ways to assess entertainment products. Magic is a special case: the phenomenological experience enjoyed by spectators is quite unique, and difficult to access. The approach developed in this framework is the use of empirically determined qualitative methods, along with quantitative measurement of straight forward enjoyment levels experienced during a performance. Further, basic qualitative probes are deployed to try to tease out problematic areas of trick designs.

When assessing entertainment, formally or informally, people often use a variety of words to describe what they have witnessed, some positive and some negative. Sometimes, the overall feeling is neither positive nor negative. Many people find it easier to express their emotional response to an experience using words, than they do using numbers or simple sliding scales, therefore using only a quantitative measure of enjoyment can be problematic.

For this work, a kind of qualitative summation of how people reacted to magic was developed, along with a numerical representation of enjoyment. Experiments were performed (number of participants, N=96) during which participants viewed videos of classic magic effects that are known to be effective. The participants were then asked to freely report a few words to describe their reaction to what they had witnessed. They were also asked to rate how much they enjoyed the experience of watching the video, on a five point scale. This allowed a way to not only crowd source the type of language people used to describe their emotional reaction to magic tricks, but also to put those words in context with how much they rated their enjoyment of a particular trick. For example, the word 'surprised' may not necessarily indicate a positive feeling; however, in the context of a magic trick, usage of this word is much more likely to be a positive response.

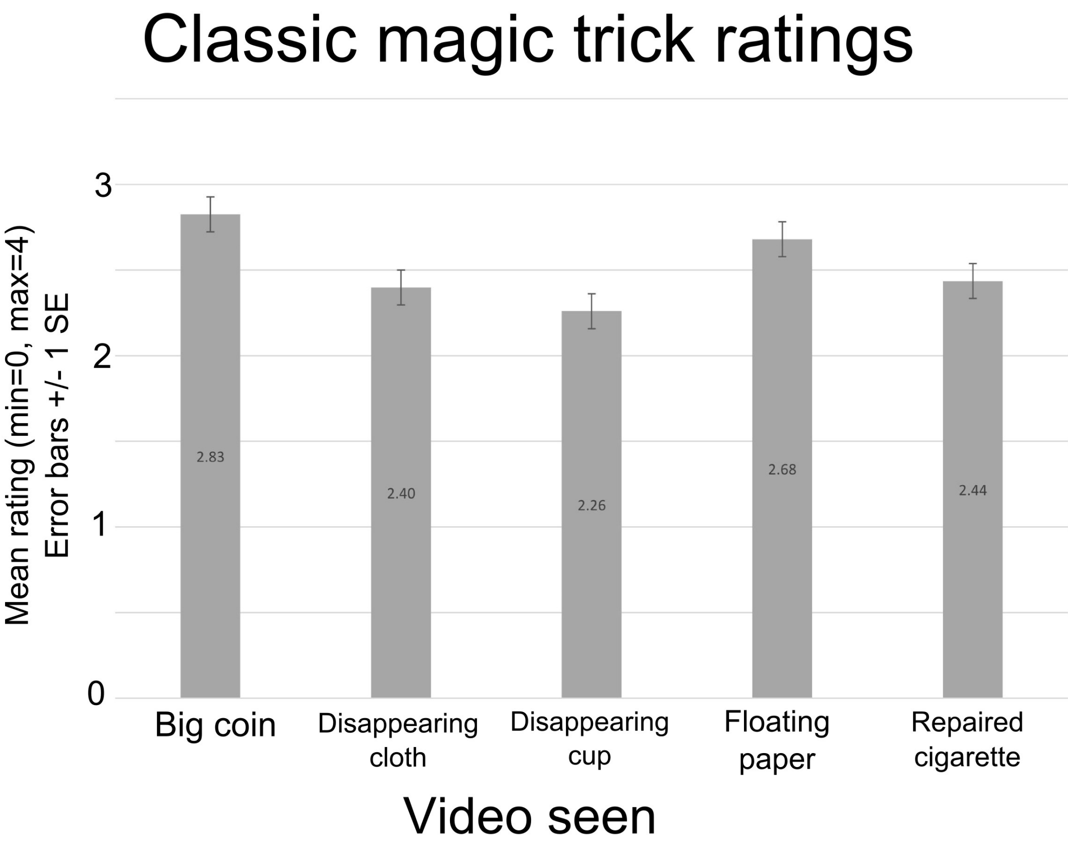
The classic tricks shown were:

1. A skilled magician showing a cup vanishing, just before the cup is smashed.
2. A skilled magician showing a piece of cloth vanishing.
3. A skilled magician showing a piece of paper floating in the air.
4. A skilled magician showing a cigarette being broken in two, then magically repaired.
5. A skilled magician showing a giant coin suddenly appearing.

The participants were recruited from university mailing lists, and from disseminating details of the experiment on Twitter. To simplify the questionnaire, age, gender, or country of origin was not requested from the participants.

See figure 4.2 on page 80 for a summary of the enjoyment scores reported for each of the classic effects. This chart can be seen as representing a base line against which the tricks developed over the course of this thesis can be compared. The classic tricks are reliable, known to be effective magic tricks, skilfully performed. A one-way within subjects ANOVA was conducted to compare the effect of video seen on enjoyment ratings in Big coin, Disappearing cloth, Disappearing cup, Floating paper, and Repaired cigarette conditions. There was a significant effect of video seen, Wilks' Lambda = 0.64, $F(4,92) = 12.99$, $p < 0.01$. Pairwise comparisons were used to make post hoc comparisons between conditions. There was a significant difference in the scores for Disappearing cup (M=2.26, SD=1.12) and Floating paper (M=2.68, SD=0.89) conditions; $p < 0.01$. There was a significant difference in the scores for Disappearing cup (M=2.26, SD=1.12) and Big coin (M=2.83, SD=0.88) conditions; $p < 0.01$. There was a significant difference in the scores for Disappearing cloth (M=2.40, SD=1.01) and Floating paper (M=2.68, SD=0.89) conditions; $p < 0.01$. There was a significant difference in the scores for Disappearing cloth (M=2.40, SD=1.01) and Big coin (M=2.83, SD=0.88) conditions; $p < 0.01$. There was a significant difference in the scores for Floating paper (M=2.68, SD=0.89) and Repaired cigarette (M=2.44, SD=0.83) conditions; $p < 0.01$. There was a significant difference in the scores for Repaired cigarette (M=2.44, SD=0.83) and Big coin (M=2.83, SD=0.88) conditions; $p < 0.01$.

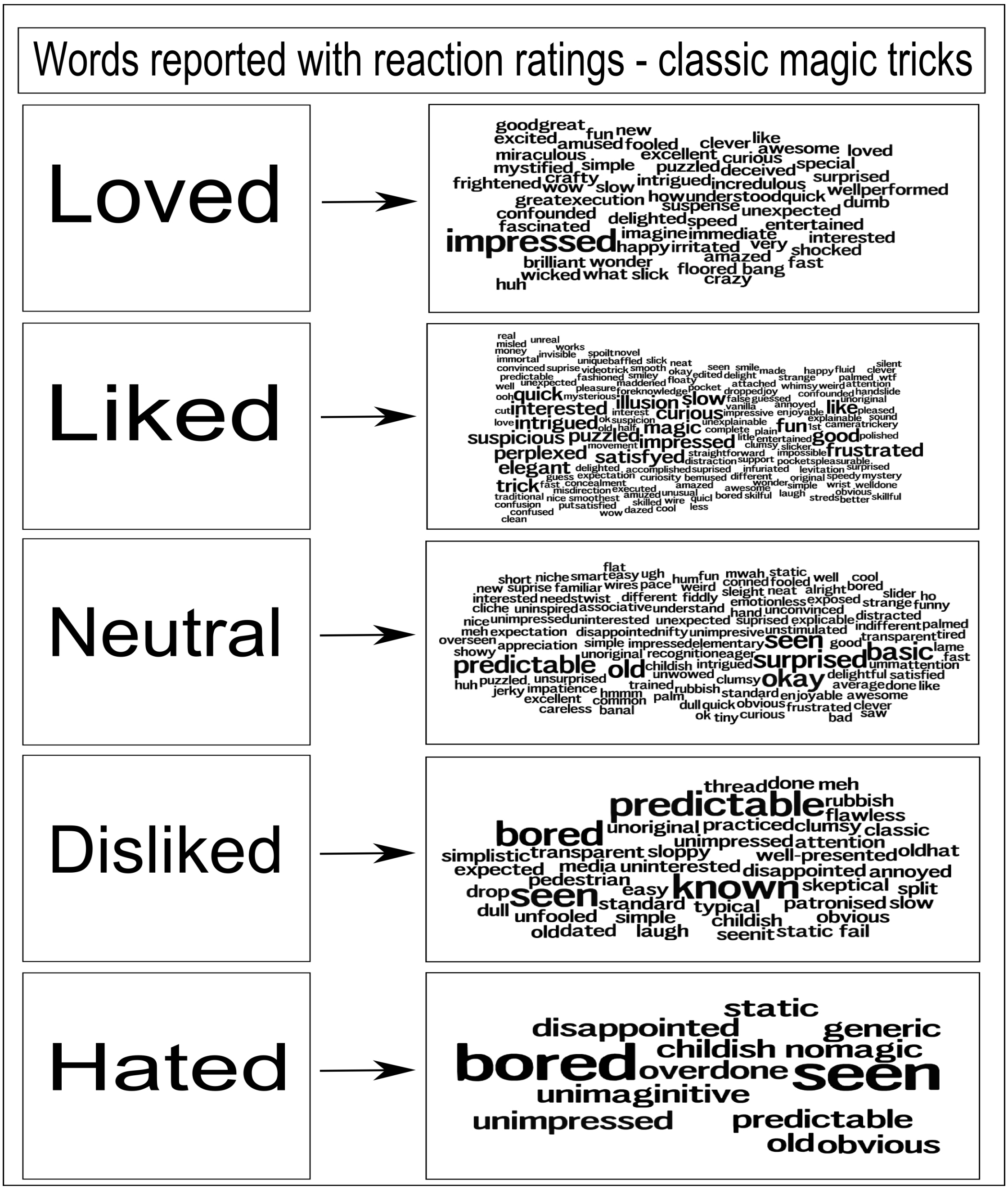
Figure 4.2 The enjoyment ratings for classic magic tricks are shown.



From all the reported words, the words most commonly used were noted. The framework uses this collection of words as options on a questionnaire for a spectator's assessment of tricks. The distilled list of words that form part of this questionnaire are: Bored, Surprised, Obvious, Neutral, Impressed, Predictable, Amazed. Words were selected that qualitatively represent an emotional spectrum of reactions to the tricks.

See figure 4.3 on page 81 for a visual representation of the words that people reported after witnessing classic magic tricks, correlated with their enjoyment score for the trick. Some words are reported at the same time as different enjoyment scores. The intention of the qualitative aspect of the evaluation method is not to translate the qualitative words into numerical scores, rather to highlight that words can have different meanings in different contexts.

Figure 4.3 Word clouds representing gathered responses from people shown classic magic tricks. The larger the word, the more often it was reported as a response to a trick.



Some people dislike magic tricks, even if they are somewhat surprised or amazed by what they have seen. Equally, a spectator may know or guess the fundamental techniques at work in a given trick, and therefore not find it to be an especially magical experience, but may still enjoy the particular presentation offered. Therefore, two scales are used on the questionnaire to capture these two types of experience: a scale on which the spectator can indicate how much, in general, they enjoy magic tricks, and also, separately, their enjoyment of the particular trick they have witnessed. An ascending enjoyment scale of 0 to 4 is used, mapped to the phrases: 'Hate(d) them(it)', 'Dislike(d) them(it)', 'Neutral', 'Like(d) them(it)', 'Love(d) them(it)'.

A calibrated enjoyment rating, that emphasises weaker tricks, can be calculated using:

$$CalibratedRating = TrickRating + (TrickRating - GeneralRating)$$

The mean general rating of enjoyment of magic reported by a group, all who viewed the same particular trick, allows the difference between this and the mean enjoyment rating of the particular trick to be calculated as:

$$DifferenceRating = GeneralRating - TrickRating$$

The lower the score the better. A number below zero would indicate that the trick had rated higher for that group than they had rated magic in general. Any score close to zero is a very good score. Should the difference between the scores be relatively high (above 1), it is an indication that, among this group of participants, the trick had been relatively disappointing.

Unfortunately, the idea to record participant's general ratings of magic came only after the classic magic trick experiment had been run, therefore it is only possible to report unadjusted ratings for these tricks (i.e. the ratings are not calibrated by a participant's rating of magic in general).

To help identify weak points in the tricks, subjects are also asked by the questionnaire to write freely about any moments in the trick when they feel something suspicious might have happened, or about how they think the tricks works.

See figure 4.4 on page 83 for an example of the questionnaire given to spectators witnessing magic tricks, developed for this work. The intention of the questionnaire is to provide a holistic view of the overall experience of a trick.

Figure 4.4 The questionnaire given to spectators of magic tricks.

Magic Trick Evaluation Questionnaire

1. Name (optional):

2. Please indicate, by circling one of the options below, generally, how you feel about magic tricks:

   Hate them! **Dislike them** **Neutral** **Like them** **Love them!**

3. Please indicate your overall reaction to the trick:

   Hated it! **Disliked it** **Neutral** **Liked it** **Loved it!**

4. Please circle the words that help describe your reactions to the trick (at least one):

   Amazed **Bored** **Surprised** **Obvious** **Neutral** **Impressed** **Predictable**

5. Please write down, as best as you can remember, any moments in the trick when you felt something suspicious was happening:

6. How do you think the trick works? Please write something here:

Collection of this data provides a numerical indication of how much a trick has been enjoyed (the key factor), and also some more qualitative data about the subjective experience of amazement, or otherwise. These findings can be compared to data collected from people that have been shown traditional, known to be effective, magic tricks. Arriving at a measure of what is experienced phenomenologically by someone witnessing a trick is difficult; this approach provides a useful, practical measure of a trick's magical and entertainment impact, without the complexity of deeper philosophical questions about the nature of magical experiences.

4.2.7 Validation [VALID]

The final component of the framework is a validation step that aims to show the viability of a created magic trick in the real world. Testing tricks through performance and assessment gives a good empirical measure of the success of the design, enabling meaningful data to be fed back to the earlier stages of the iterative development process. To validate the overall effectiveness of the framework, this thesis argues that the most useful measure is one of the simplest: to sell the created tricks to magicians, via a reputable magic shop. The reasoning behind this approach is that a shop being willing to sell a product demonstrates a base level of quality for that product, as assessed by experts (specialist retailers). Davenports[1] in London, UK, were approached, and agreed to include suitable tricks created by the framework in their inventory. Sales of the trick demonstrate that, having considered their retail options, real people have decided to part with real money to acquire the trick.

[1]Davenports were founded by Lewis Davenport in 1898, and have been in the same family ever since; they are the oldest continuously owned magic shop in the world.

4.3 Summary

This chapter presented a framework approach to designing, optimising, and evaluating magic tricks. The framework is flexible enough to deal with the creation of new tricks, or the optimisation of existing tricks. Crucially, the framework allows for the identification of specific parts of a trick's methods, both physical and psychological, that may be amenable to optimisation, either computationally or otherwise. Where computational optimisation is of benefit, a suitable technique may be deployed in a modular fashion appropriate to the structured problem domain formalised as part of the framework process. The processes described should be capable of integrating the various elements of a trick for both the performer and the spectator into an optimal, or near optimal, presentation. This output can then be evaluated and validated using the outlined methods, enabling the success of otherwise unrelated tricks to be measured and compared. The next chapter shows the first steps taken with the framework: applying some of the processes outlined in this chapter to a real trick, in an attempt to optimise it.

Chapter 5

First steps with the framework

As described in Chapter 4, in principle any magical effect can be formalised and optimised using some or all of the framework components described. This chapter presents a case study in miniature to demonstrate some of the features of the described framework. The idea of this small project was to show how an existing magic trick could be de-constructed with the framework, potentially optimised, extended using technology, and evaluated in the field. The Princess card trick, a well known effect, was selected, as it is a simple effective trick that can be easily discussed without getting tangled in method discussions. Here, the framework process is described, and the results of testing the final trick are shown.

5.1 The Princess card trick

5.1.1 Background

The Princess card trick was invented by Henry Hardin in 1905. Subsequently, it has been performed by many magicians including Ted Annemann, Dai Vernon, Lewis Ganson, John Hilliard and Lance Burton. The trick is very simple in operation, and highly effective. A participant is shown a small number of cards, and asked to secretly select one. The performer then turns the cards away from the spectator, removes one, and shows them to the spectator again. Magically, the card the spectator had selected has been removed. This trick has many online versions.

Technology has previously been used as a presentational device in magic tricks; famously Penn and Teller's 'World's Most Expensive Card Trick' [214], performed during a live television broadcast, convinced watching spectators that the technology used was performing an impressive feat to reveal a participant's freely chosen card, where in fact the method was entirely reliant on an accomplice. The chosen card was displayed on a large electronic advertising board in Times Square, New York, USA. The setup of the trick was interesting as it convinced the television audience that they were in on the deception, when in fact they themselves were being deceived (and entertained).

The Japanese company Tenyo produce a number of mobile phone apps to present well known, and phone specific, magic tricks [215].

Online tricks, similar to the Princess trick, such as Bumgardner's iPolygraph [216], use a communication code between the performer and the computer to pass information about a spectator's choices. Litchfield's 'Mother of All Online Card Tricks' [217] uses a remote accomplice to pass information to a computer: the spectator visits a web page under the supervision of the performer, names a playing card, and has it revealed to them on the page - a third party listens in on the performance, and activates the relevant card on the web page remotely, at the appropriate time.

The Princess card trick was used as a proof of concept case study to test the framework methodology, and to develop its structure and components. The idea was to take a trick and apply the framework, see how effective the process could be, and identify weaknesses along the way. That process is now described.

5.1.2 The trick [MAGIC]

During this phase, as outlined in chapter 4, the various effects and magical techniques available are researched via consultation with domain experts, discussions with magicians, and research of existing literature. The Princess trick is widely known, and is a straightforward effect with simple methods behind it. The trick is described:

- The performer shows the faces of a number of cards, four or five, to a spectator.
- The spectator secretly selects a card, remembering it.
- The performer shuffles the cards, showing the backs to the spectator.
- The performer removes a card, intimating to the spectator that they know the card they are thinking of.
- The performer shows the faces of the remaining cards to the spectator. The spectator's card has been removed.

There are a variety of methods to implement this effect. The underlying method is very simple:

- The cards that are initially displayed to the spectator are all different to the final group of cards.
- No matter which card the spectator picks, it will not be in the final group.

The trick relies on the visual similarity of the cards across the groups, causing the spectator not to notice that they have all changed, only that the card they have chosen is no longer present. The trick is remarkably effective, though now widely known, so the chances of performing it to someone that has not seen it before are somewhat reduced. Sometimes the cards will be gimmicked so that half of each card displays the value and suit of one card, while the other half shows a different value and suit. Skilful magicians are able to manipulate the cards so that a spectator will only ever see the desired half of each card. See figure 5.1 on page 90 for an example set of cards [218].

At this stage of the analysis, it was noted that the Princess trick is well suited to a digital, or remote, performance, using cards on a display screen. There is a key question to answer about how effective magic can be when presented via well known digital methods that are known to excel at trickery. As discussed in chapter 2, while things like visual effects in film are astonishing to witness, they are not experienced by an audience as a magic trick, as nothing outside the normal physical rules of the universe seems to have occurred; general audiences are knowledgeable enough to understand that visual effects are created by computers, and are not real. Performing a magic trick on a computer of some kind presents its own challenges and questions. To investigate these, the use of a mobile phone suggested itself as a presentation device; convenient for a magician to carry with them, and capable of general computation and presenting animated images of playing cards.

5.1.3 Psychological factors [PSYCH]

As the trick is simple and well defined, and not a new design, it was straight forward to look at existing versions of the trick, and analyse the psychological factors involved. When the trick fails, no magical effect is experienced, as the method is determined by the spectator. The impact of the effect is at its peak when an audience is focussed on the disappearance of their own card, which inevitably occurs.

Table 5-A on page 91 outlines the various psychological factors, and relevant parameters, identified for the Princess trick.

There is an obvious question to investigate about whether using different groups of similar cards may yield a better trick - one that is less often detected, and is experienced as more magical.

The second set of factors around card manipulation and skill level may be neatly

Figure 5.1 The traditional version of the Princess card trick.

Psychological factor	**Relevance**	**Parameters**
The trick relies on the spectator not noticing that the two sets of cards shown contain entirely different cards.	Spectator.	1. The cards chosen for the initial set. 2. The cards chosen for the final set.
In some methods used to implement this effect, there may be a range of techniques that rely on the manual dexterity of the magician to show the correct areas of each card.	Spectator and performer.	1. The particular technique chosen. 2. The skill level of the magician.

Table 5-A: Psychological factors in the Princess card trick.

sidestepped by using a mobile phone, or other computer, as a presentation device. This way, no manual dexterity is required by the magician, and the remaining factor is one of narrative. The question remains of whether an audience would accept a magic trick performed on a sophisticated piece of technology.

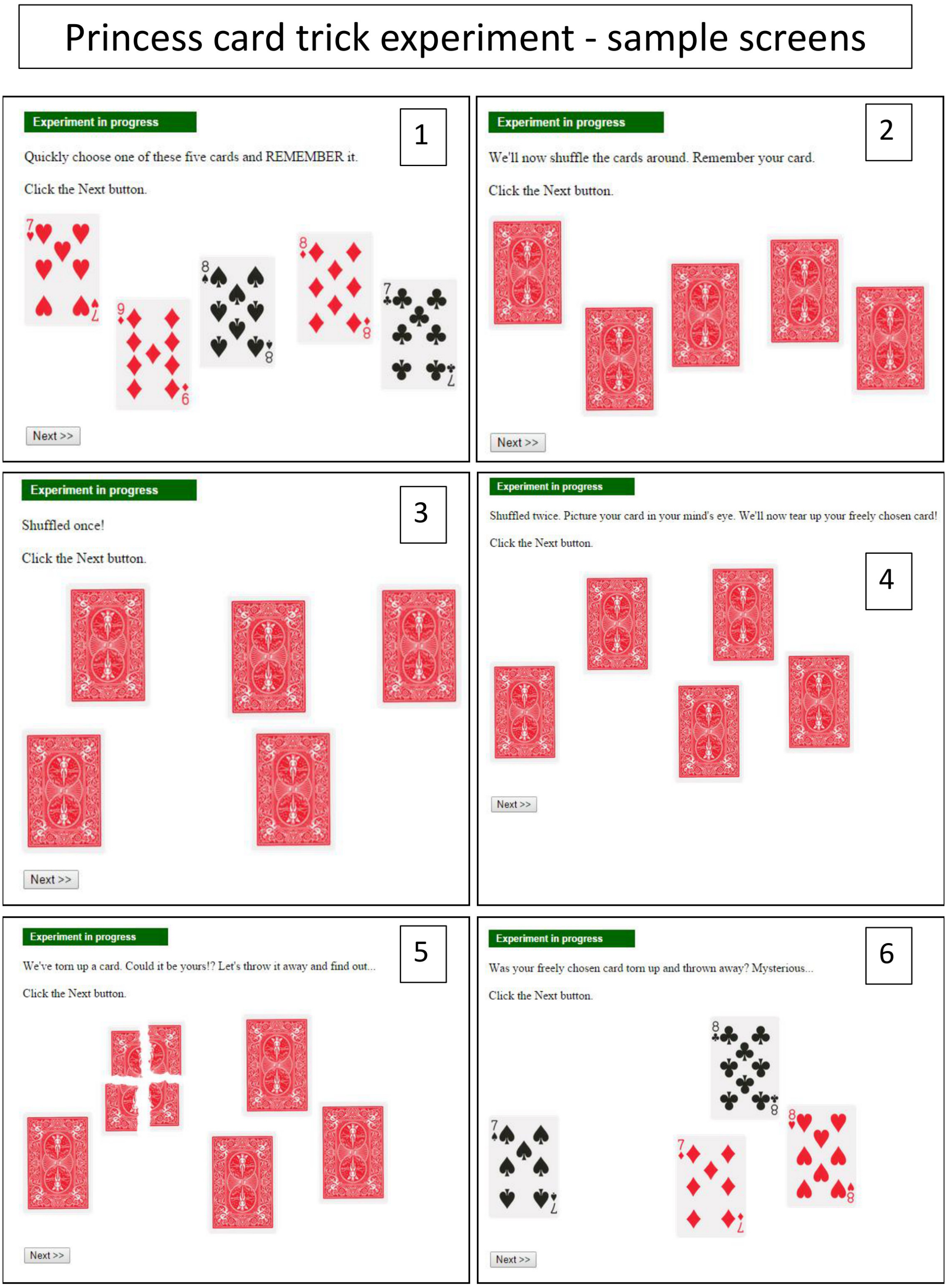
To determine the best sets of cards for use in this trick, a simple on-line experiment was performed in which the trick was played out for participants, who were then asked to rate the trick and provide feedback about their experience using a version of the framework questionnaire.

5.1.3.1 The Princess experiment

The trick was shown to participants (N=118), via a web site. At the beginning of the trick, a participant is asked to quickly select one of the on-screen cards and remember it, before moving to the next screen. Four consecutive screens were then shown displaying the face down cards in changing positions. At the end, an image representing a torn up card as one of the cards is shown, and then 'thrown away', before the faces of the remaining cards are displayed. It is worth noting here that the participant is in complete control of the pacing of the trick, which will inevitably lead to a poorer effect if they are overly curious, or do not follow the on-screen instructions precisely.

See figure 5.2 on page 93 for an example of the screens the participants viewed during the experiment.

Figure 5.2 An example experiment sequence shown to participants, who were then asked to rate the trick they had seen. Each screen was shown in turn. Crucially, the participant is in control of the timing of each screen, and there is no magician to interact with.



The different sets of cards used in the experiment were chosen by consulting domain experts, and by also speculatively selecting sets for comparison, based on simple criteria. Seven sets were used for the experiment. Each participant saw the trick only once, viewing a random set. The experiment can be seen as an attempt to optimise the trick, a way of discovering an optimal set of cards for use in the Princess card trick.

5.1.3.2 The Princess card sets

The first set is the same as that used by Lance Burton in a television appearance [219], where he performed the trick for viewers watching at home (in much the same way that the trick is performed remotely on the experiment web page). He uses a collection of red and black face cards, carefully chosen to be similar, with none of the cards really standing out. One higher value card appears in the initial group (a king), which is removed in the final group. This way, there can be two queens and two jacks in both the initial and final groups, without replicating a card.

The second set was put together by observing the suits and arrangement of the cards in Burton's set (whether to place red cards next to black, and which value cards should be adjacent in each group), and mimicking these while replacing the face card values (jack, queen, king) with midrange values between seven and nine; as with Burton's set, there is one higher value card in the initial group (here, it is a nine), which subsequently disappears in the final group. Peter McOwan of Queen Mary, University of London, has extensively tested a similar set of midrange cards at many lectures around the UK, presenting them on slides to large audiences. Again, this is similar to the way in which the trick is presented during the on-line experiment.

The third set was chosen speculatively as a combination of Burton and McOwan's cards. It is composed of a mixture of red and black cards with a mixture of midrange and face cards. As the trick seems to rely on the similarity of the sets of cards, the hypothesis for this set is that the method would be more easily detectable, and hence the trick would fail more often.

For the fourth, fifth, and sixth sets, work on the likeability of certain playing cards by Olson et al [56] was noted; they provide an experimentally determined index of how likeable playing cards are. The idea for these sets was to pick cards with the assumption that a likeable card would more easily draw the eye; thus, a likeable card in a group of not so well liked cards should stand out in some way.

The fourth set plants a very likeable face card (the King of Hearts) amongst other visually similar, but less well liked, face cards in the initial group, leaving only other similar face cards in the final group.

The fifth set shows a likeable card (the Ace of Hearts) with other, less well liked, face cards in the first group, similarly being removed in the second group of face cards; here, the Ace of Hearts is visually dissimilar to the other cards (there is much more white space on the design), as well as being the most likeable card in the initial group.

The sixth set is composed of five likeable, visually similar, face cards together in the initial group, followed by four not well liked cards in the final group.

Given that detecting the method of this trick relies on being able to recall, even if not specifically, each card in each group, it was hypothesised that each of these sets would perform less well than the sets chosen by the domain experts.

For the fourth set, the presence of a likeable card amongst visually similar cards in the initial group might increase the probability of it being noted to be absent from the final group (obviously, only if it was not the card chosen by the participant); this would naturally lead to the idea that all the cards have been changed. Similarly for the fifth set, though here the effect might be even more pronounced, as the cards are also visually dissimilar to the liked card. For the sixth set, it might be very obvious that all the cards have changed, as the participant views five well liked cards, followed by four less well liked, which might lead to an overall feeling that all the cards have changed.

Origin	Cards	N=
Burton (red and black face cards)	1. $J\heartsuit, K\diamondsuit, Q\spadesuit, Q\diamondsuit, J\clubsuit$ 2. $J\spadesuit, J\diamondsuit, Q\clubsuit, Q\heartsuit$	16
McOwan (midrange value red and black cards)	1. $7\heartsuit, 9\diamondsuit, 8\spadesuit, 8\diamondsuit, 7\clubsuit$ 2. $7\spadesuit, 7\diamondsuit, 8\clubsuit, 8\heartsuit$	18
Mixed red and black midrange value and face cards	1. $J\heartsuit, 9\diamondsuit, 8\spadesuit, 8\diamondsuit, J\clubsuit$ 2. $8\clubsuit, 8\heartsuit, J\spadesuit, J\diamondsuit$	13
One liked card among visually similar red and black cards, like card is removed	1. $J\diamondsuit, K\heartsuit, Q\clubsuit, Q\diamondsuit, J\clubsuit$ 2. $J\spadesuit, J\heartsuit, Q\spadesuit, Q\heartsuit$	14
One liked card among visually dissimilar red and black cards, like card is removed	1. $J\diamondsuit, A\heartsuit, Q\clubsuit, Q\diamondsuit, J\clubsuit$ 2. $J\spadesuit, J\heartsuit, Q\spadesuit, Q\heartsuit$	18
All liked red and black cards, then all not well liked red and black cards; all visually similar	1. $Q\heartsuit, K\heartsuit, Q\spadesuit, Q\heartsuit, J\spadesuit$ 2. $J\clubsuit, J\diamondsuit, Q\clubsuit, Q\diamondsuit$	14
Low valued red and black cards	1. $3\heartsuit, 5\diamondsuit, 4\spadesuit, 4\diamondsuit, 3\clubsuit$ 2. $3\spadesuit, 3\diamondsuit, 4\clubsuit, 4\heartsuit$	20

Table 5-B: Card sets tested with the Princess trick. Number of participants (N=) is shown for each set.

The final, seventh, set of cards was chosen to be composed of all low valued red and black cards ranging from three to five in value. This provides the lower end version of Burton's high valued face cards and McOwan's midrange cards.

Table 5-B on page 96 shows the cards used in each set, and how many participants viewed the trick with this set.

5.1.3.3 The results of the Princess experiment

Participants (N=113) were asked to provide their age, gender, and country of origin, along with a rating of how much they had enjoyed the trick on the scale: 'Hated it!', 'Disliked it', 'Neutral', 'Liked it', 'Loved it!'. This was mapped to numerical rating values 0 to 4.

Participants were 42% male, 58% female. Participants ages were 52% 18 to 30, 27% 31 to 40, 13% 41 to 50, and 8% 51 or over. Participants countries of origin were 49% USA, 34% UK, 3% Australia, 3% Canada, with the remaining 11% made up from Austria, Brazil, Germany, Greece, Ireland, Italy, Mexico, New Zealand, Romania and Spain.

See figure 5.3 on page 99 for the ratings results of the experiment. A one-way between subjects ANOVA was conducted to compare the effect of card set on enjoyment rating for card sets in Burton, Mcowan, Mixed value, One liked (similar), One liked (dissimilar), All liked, and Low value conditions. There was a non-significant effect of card set on enjoyment rating at the $p < 0.05$ level for the seven conditions [$F(6, 106) = 1.79$, $p = 0.11$]. Initial results suggest using more subjects in the experiments may result in a significant difference between sets.

Although the results do not come down conclusively in favour of any one set of cards, some interesting overall lessons can be learned. As would be expected, the existing domain expert's set performed well. In fact, the professional magician's choice of cards was the equal best performing set, matched only by the low valued set. This is interesting, as each set is at opposite ends of both the value and likeability spectrum. It is plausible to argue that low valued cards, that are generally not well liked, are unlikely to draw much attention during the presentation of the first set of cards; thus, no one card will stand out to the participant in either group, which they may subsequently identify as being the odd one out, alerting them to the underlying method. Similarly, the face cards used by Burton have a balance between the groups; the well liked $J\heartsuit$ in the first group is matched by the also well liked $Q\heartsuit$ in the second. Similarly for the generally less well liked black suits and diamond suits. There is no incongruity between the groups.

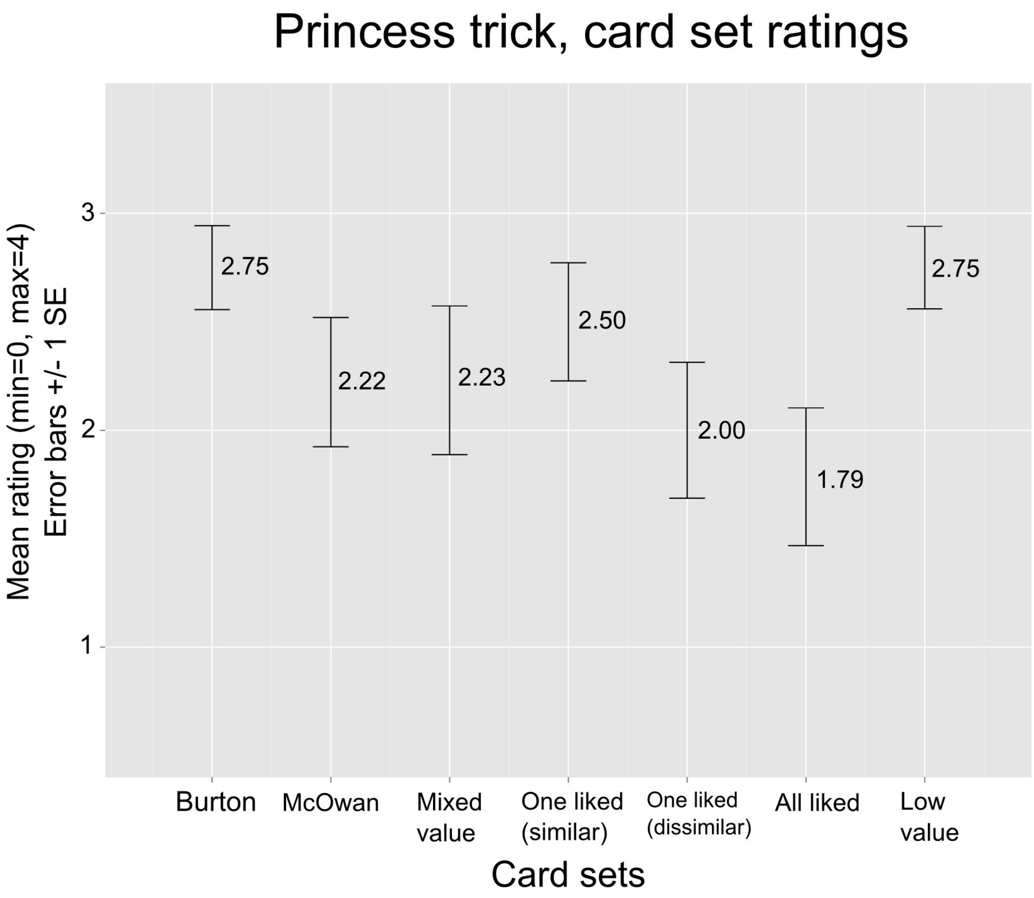
The fourth set, with one very well liked card, the $K\heartsuit$, appearing in the first group amongst other less well liked cards, is the next best performer. Presumably the well liked card may be particularly salient to some participants, who recognise its absence in the second group.

The second and third sets are the next best performers; McOwan's set (the third) is made up of mid range value cards in each group. These are generally not well liked, and none should be particularly memorable, however it may be that the 9$\diamondsuit$ is salient enough in the first group to attract attention for some participants. The mixed third group is by definition made up of incongruous cards, however as each group is composed of mixed value cards there may be enough similarity between the groups to obfuscate the method.

Finally, the worst performing were the fifth and sixth sets. The fifth set has one well liked card mixed in with four visually dissimilar cards in the first group, which presumably causes it to stand out, and subsequently be missed in the second group. The sixth group has the property that each group, taken as a whole, are at different ends of the likeability spectrum, which most likely alerts participants to the idea that all the cards have changed.

While it may appear that the experiment has not yielded a new optimum set of cards, it has provided concrete evidence that magicians are in fact themselves very good intuitive optimisers of magic tricks. The low valued set suggested by this experiment is interesting because it is not one usually used for this trick, yet performs as well as the best set used by a professional magician. This is encouraging for the framework, as even this very simple experimental process has provided an insight into potential new ways to approach the Princess card trick.

Figure 5.3 The mean ratings for each set of cards deployed in the Princess card trick on-line experiment. As can be seen, Lance Burton's set and the set of low value cards were scored highest, on average, suggesting they are the most effective sets.



5.1.4 Controlled problem domain [DOMAIN]

For this first step with the framework, the Princess trick was not formally abstracted in a way that would allow computational optimisation; the focus was on investigating the outcome of a simple optimisation process based on experimental psychological factors. There would appear to be some future work that could be done in automating this experimental process by determining a computational model of the perception of the cards, taking into account the saliency of any one card in a group, and the overall visual similarity between the two groups. An algorithm can be imagined that finds optimal combinations of cards to minimise/maximise these visual properties, though this is not investigated here. Computational techniques are integrated into the design process by the framework in increasingly deep ways as the thesis progresses, as will be seen in the coming chapters and case studies.

5.1.5 Computational technique [AI]

As there is no problem domain, there are no computational techniques to identify. This area will be fully explored in later chapters.

5.1.6 Technology [TECH]

To investigate the use of digital media technology in magic tricks, a mobile phone app was developed to present a version of the Princess card trick. This removes the need for manual dexterity on behalf of the magician, and in fact makes the trick accessible to a very wide range of performers. Though the main focus here was to investigate whether a mobile app could be a credible performance device for magic, it has the added benefit that the trick is performed in a very similar way each time, which is helpful for consistency of data. As the trick is entirely self working, the magician is also freed up to concentrate on delivering the presentation in the best way possible.

The app presents the trick as follows:

1. A initial screen showing the backs of five playing cards is shown.

2. The performer instructs the spectator that the cards will be turned over so their faces are showing, and that when this occurs the spectator should quickly choose and memorise one of them.

3. The performer touches the screen once, flipping over the cards, and waits for the spectator to indicate that they have memorised a card.

4. The performer touches the screen, and the cards backs are shown again.

5. The performer tells the spectator that the cards will now shuffle themselves on screen, and that they must follow their chosen card around the screen as best they can while all the cards are changing positions.

6. The performer touches the screen, and the cards begin to move, slowly at first, changing positions. Gradually the cards move faster and faster until it becomes impossible to follow the location of any one card. The cards come to rest at their final positions.

7. The performer asks the spectator if they managed to follow their card, which they can not have done.

8. The performer states that despite this, it is likely that deep down in their subconscious they know which of the cards on screen is their selected card. To prove this, they should get rid of their own card by flicking it off screen.

9. The spectator chooses a card, and flicks it off screen.

10. The performer touches the screen, and all the cards display their fronts. The spectator's card has been removed.

This particular presentation has the benefit that the spectator is able to physically interact with the mobile phone, which may improve the cognitive illusion that there are five real cards on screen that are unable to change their values during the trick.

5.1.7 Evaluation [EVAL]

The most effective card set, according to the experimental data, was selected to be used in the app. The new low valued set (the seventh) was chosen in preference to Burton's set, as it is a previously unused set of cards for this trick. The app was configured with the set, and taken to a science festival (Big Bang, at Westminster College on July 2nd 2014). Random participants (N=24) were shown the trick on a mobile phone and asked to fill out the general framework questionnaire outlined previously, reporting their overall liking of magic, how much they enjoyed this particular trick, words chosen from the distilled framework set (derived experimentally as previously described), any moments that they felt were suspicious during the trick, and how they thought the trick worked. The ratings were compared to the ratings from those gathered for the classic magic tricks (N=96), reported in section 4.2.6.1 on page 77.

The trick received a mean rating score of 3.58 (out of 4), comparing favourably with the scores reported for the classic tricks (though they were presented without a narrative), with no scores lower than 3. The reported mean rating of magic in general was 3.79 (out of 4). The scores are high, possibly reflecting the enthusiasm of the age group for magic (ages were not recorded, though ranged from approximately 8 to 16), and also the fact that the participants were self-selecting in terms of enjoying magic tricks, as they chose to approach a stall that advertised itself as being magic related. Nevertheless, the trick received a high score.

It is assumed that when reporting overall enjoyment of magic, a participant will tend to report their best experience of magic in the past, rather than some mean score that they calculate. Most people that love seeing films in a cinema will have seen poor quality productions, though they are likely to report that they love films in general. Therefore, it should not be expected that a trick will receive a rating that exceeds, on average, the overall rating of magic that people report (though this is possible for truly exceptional tricks). A key indicator is how close to this overall enjoyment score the trick is rated.

Here, the difference is 0.21, a good score.

Table 5-C on page 103 summarises the results.

Trick	**Mean enjoyment score reported for the trick**	**Mean enjoyment score reported for magic in general**	**Difference**
Princess card trick	3.58	3.79	0.21

Table 5-C: Summary of enjoyment scores reported by a group viewing the Princess card trick. Lower Difference scores are better.

As discussed, the participant's selection of words to describe the trick they have witnessed is intended to provide an alternative qualitative view of the experience. It is possible that weaknesses in the trick may be indicated by the words people use to sum up the trick, even if they report enjoying it. Participants were asked to select as many words as they wished from: Bored, Surprised, Obvious, Neutral, Impressed, Predictable, Amazed.

The following word counts were received (there are more words reported than there are participants, as each participant was free to select as many words as they wished): Amazed (8), Surprised (8), Impressed (10), and Neutral (3). All three Neutral responses scored the trick 3 out of 4, however two reported enjoyment in general as 4 out of 4, the other 3 out of 4. Interestingly, each of these participants detected the method of the trick (reported in their responses to the question of how the trick worked), though neither reported any suspicious moments during the trick. None of the other participants reported the correct method behind the trick.

Of the 24 participants, 5 guessed that the mobile phone itself was doing some kind of sensing of their voice, or tracking their eye movements. All the rest could not suggest a coherent method.

Suspicious moments, reported by 8 participants, were during the shuffling phase, or when the performer asked what the participant's card was. Both of these aspects of the trick are merely distractions from the real method (the trick would work, mechanically at least, without any shuffling, or the performer knowing the actual card the participant had chosen).

The most interesting aspect of the results from this field test were those pertaining to the role the mobile phone played in the trick. The rating of the trick (good) suggests that participants had experienced a magical effect, not detracted from by the presence of the mobile phone.

It might have been expected that using digital cards would render this particular trick ineffective. When their backs are shown, there is no guarantee that the card faces stay the same; they are just pixels on a screen, able to be easily changed by the computer. While this success was entirely predictable from the results of the online experiments to determine the most effective set to use, it was interesting to note that the magical experience is not broken by combining a human performer with a computational device, and that the trick compared favourably with participant's overall rating of magic. In fact, the rating of the trick scored more highly on the mobile phone than online: up from a mean rating of 2.75 to 3.58; however, as the overall rating of magic was not recorded for the online tests, this higher score cannot be calibrated as a differential.

It may be that performances by physically present magicians will generally be scored more highly, or that the self-selecting group that viewed the trick at the science fair were more likely to enjoy magic of any kind, or indeed that the presence of a performer causes people to be more generous in their reports of magical enjoyment. For these reasons, the difference between the overall rating and the specific rating can be seen as the best measure of a trick's performance.

5.1.8 Validation [VALID]

The final step of the framework process is to further validate the trick that has been produced. The proposed method for doing this is to productise the trick and sell it to a target audience: magicians.

The mobile phone app created for field testing is an ideal product to sell. The app was made available on the Google Play store, for Android based mobile phones. Selling apps on the store is notoriously difficult without some kind of publicity. To this end, the famous Davenports magic shop in London, UK, were approached with the idea of marketing the app through their website. They agreed, and the app remains for sale via this mechanism.

This partnering with a reputable shop further validates the produced trick, regardless of sales, as it is assumed that a product must be of a basic quality before the shop will agree to be associated with it (either by keeping the trick as an item in their physical inventory, or by linking to it in digital form); niche shops of this kind thrive on their reputation for providing quality products.

In a post-launch period of two weeks, the app sold 17 copies to magicians; not a large figure, but further evidence as to the viability of producing tricks with the framework.

The key point to note at this stage of the development of the framework is that the overall process of optimising a magic trick has been successfully carried out, from initial analysis through to evaluation and validation. Though the sales numbers are small, they are real - people are willing to spend money on a new version of a classic, well known trick, produced using the proposed framework.

5.2 Summary

A simple case study has been presented that shows some of the framework components in operation, and an argument has been made that magic tricks, even existing classic effects, can be optimised. Mobile phone technology has been shown to be a viable option for magic presentations. The next chapter explores the use of the framework for the creation and optimisation of novel magic tricks, and introduces computational assistance to the framework, aiming to improve the optimisation process.

Chapter 6

Introducing a computer into the magic trick design process

The concept of optimising an existing magic trick using the proposed framework has been shown in the previous chapter. In this chapter further steps are taken with the framework, introducing the use of a computer as an aid in the trick design process to tackle combinatorial problems that arise in many types of trick, and as a natural language data sourcing and processing tool. Crowd sourcing of psychological concepts for use in the framework process is investigated; further, the role of human associative memory and its potential exploitation in magical effects is explored. Two new tricks are developed and evaluated: a physical card trick, and a trick that relies on a mobile phone for presentation; the latter is used as a basis for making a further case for using sophisticated technology in plain sight in magic trick presentations.

6.1 The Association card trick; words and images

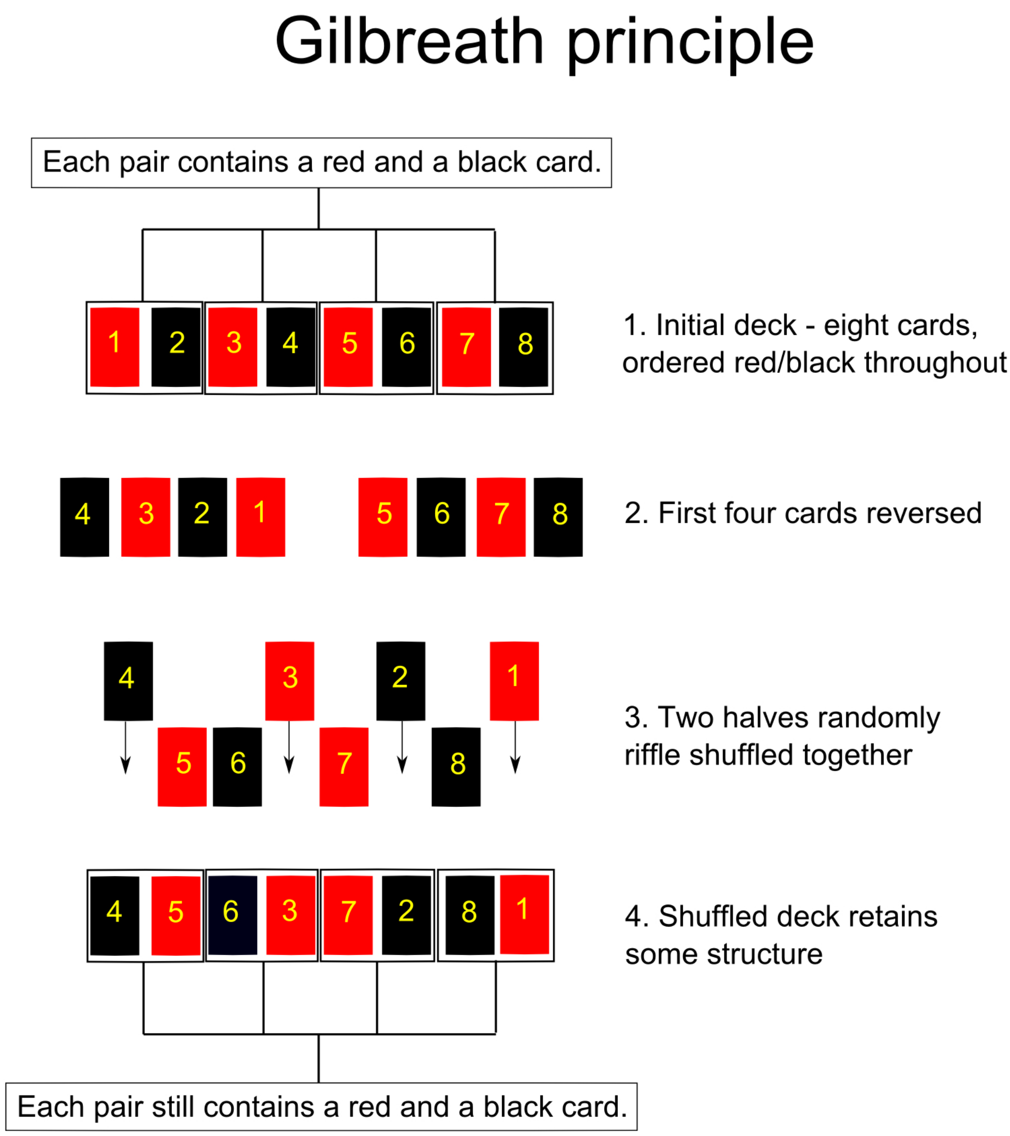
6.1.1 Background

As noted in chapter 2, there are many different types of magic trick. After using the framework to optimise an existing trick in the previous chapter, with some success, the obvious next step was to try to build a new trick using the framework. With magic, as with most creative disciplines, there is very little that is entirely new; most creations are modifications, or syntheses, of existing artefacts. The process of designing a new magic trick has the potential to highlight aspects that could be automated or improved via a computational technique. A new trick was imagined, drawing on various concepts in the existing literature of magic and psychology, that posed problems that suggested a computational solution. First, the various elements of the trick are discussed, before the structure of the trick itself is detailed.

6.1.1.1 A card trick based on the Gilbreath principles

A card trick is a good starting point for the creation of a new trick; there are many known techniques available, and rich potential for new ideas to be implemented. Norman Gilbreath provided, in 1958, an interesting and ingenious set of techniques that card magicians are able to exploit in numerous ways: commonly referred to as the Gilbreath [30] principles. These findings show that a deck of cards (or any sequence of objects) ordered in categorical groups, maintains, after one riffle shuffle, the property that all sequential groups in the deck are guaranteed to be composed of one of each card from each group, though not necessarily in the original order. Prior to the shuffle, the order of one portion of the deck must be reversed. See figure 6.1 on page 109 for an example. Many card tricks detailed by, amongst others, Mactier [29], use these principles to great effect.

Figure 6.1 An example of the Gilbreath principle. Eight cards are ordered red/black throughout. After reversing half the deck, and performing a riffle shuffle, each sequential pair still contains a red and a black card.



Often card tricks rely on sleight of hand to manipulate cards that spectators have, supposedly secretly, selected. A performer may skilfully keep track of cards, in order to later, seemingly magically, reveal them. A classic type of effect is of the kind ‘select a card, any card', which the performer then guesses. Essentially this type of trick gives the participant the illusion of a free choice, which the performer is somehow able to divine. As we shall see, there are other ways to determine a spectator's choices, that do not involve sleight of hand.

6.1.1.2 The associative mind

The human mind, as we have seen in chapter 2, is a powerful associative machine. Representations can very easily be connected to one another, even when they are of different types: for example, images and words. Saying the word 'dog' to an English speaking person will automatically trigger a number of associated mental representations. One of these representations is very likely to be some kind of visual representation of a dog, called to mind without effort. Printed words play a similarly direct role in associative mental processes.

6.1.1.3 Automatic thinking

Kahneman [220] has shown that the human mind appears to rely on two different psychological systems, which he terms System 1 and System 2. System 1, in Kahneman's view, takes care of much of the seemingly automatic, yet sophisticated, mental processing that goes on in day to day life. A basic example of this in action, is the mental calculation required to evaluate x in $x = 2+3$. This calculation happens so rapidly as to appear to our conscious minds as being an automatic process. Similarly automatically, the complex set of mental and physical processes required to pour some water into a glass and drink the contents is performed effortlessly, without error.

In contrast, consider calculating the value of x in $x = 373+259$. Eminently calculable, with a little effort. The small amount of mental effort required to add the two numbers is an example of System 2 type thinking: active, conscious, applied thought for problems such as calculation, or planning. System 2 is the type of thinking that is able to, for example, solve puzzles by way of rational, contemplative thought. The same type of thinking can be applied by a spectator witnessing a magic trick, and may lead them to an understanding of the underlying method, spoiling the effect. It is this type of thinking that a magician will want to minimise during a performance. Equally, a performer will want to maximise the amount of System 1 type automatic thinking, that is far more easily misled. Kahneman shows that given a choice between deploying the two systems to solve a given problem, most people will be comfortable accepting the immediately available solution presented by System 1.

6.1.2 The trick [MAGIC]

Considering these mathematical and psychological factors, a mind reading prediction effect reliant on a set of custom playing cards was imagined: the performer goes through a routine, during which the spectator is asked to make a seemingly free choice between certain presented options; after a card has been selected, the performer is able to reveal that this choice had been previously predicted by them.

To achieve this, the performers uses a physical set of playing cards that can be manipulated according to the Gilbreath principles, along with the knowledge that the human brain finds associations between mental concepts very quickly and easily. Further, Kahneman's observations around System 1 thinking are built into the presentation of the trick, to engineer a situation for a participant whereby they will be asked to quickly make a choice between some associative options presented to them - in doing so, applying a kind of psychological force.

As will be shown, the choice the spectator makes can be reliably predicted based on the assumption that their System 1 thinking will give them an easy and automatic association for only one option, which they will take (mostly). This 'easy way out' is crucial; the brain's powerful associative machinery means that, given sufficient time, a spectator may deploy their System 2 processes, and subsequently start making unforeseen associations.

For ease of reference, the trick will be referred to as the **Association** trick.

6.1.2.1 Template for the Association trick

A template for the Association trick was designed, using two sets of cards, which will now be described. One deck contains 16 distinct images, the other 16 distinct words, one per card. The words and images are derived from pre-defined conceptual categories. In each deck there are four separate categories, with four images, or words, in each.

The crux of the trick is that, in all, there are seven conceptually distinct categories used; one duplicate category is deployed in both the deck of words and the deck of images. The trick relies on the spectator selecting a word, and coupling it with an image, from the conceptually similar category in each deck. We will see how these categories are generated below.

Using a numerical digit to denote a card from a given conceptual category, the cards in each deck are initially ordered as:

- Word deck: 1, 2, 3, 4, 1, 2, 3, 4, 4, 3, 2, 1, 4, 3, 2, 1
- Image deck: 1, 5, 6, 7, 1, 5, 6, 7, 7, 6, 5, 1, 7, 6, 5, 1

There are two things to note: the sequential ordering that is reversed halfway through each deck, and the appearance of category 1 in each deck. The second Gilbreath principle (which generalises the first principle) states that any sequentially ordered set of objects will retain elements of structure after one riffle shuffle.

To be clear, a riffle shuffle is one set of interleaving operations performed on two parts of a deck; a deck is split into two sections, and randomly shuffled back together once. Usually, in Gilbreath based tricks, a sequentially ordered deck is split by dealing any number of cards face down from the top of the deck, which reverses their order. These cards are then riffle shuffled back together with the remaining cards from the deck. See Diaconis [30] for further explanations and explorations of these principles.

In the Association trick, half the deck is pre-reversed, as shown above. The structure that remains after one riffle shuffle is that there is guaranteed to be one card from each category in each set of cards of appropriate length (here, four) dealt from the deck, though the ordering is now unknown. For the Association trick this means that, if each deck is riffle shuffled, dealing groups of four cards from the Word deck will yield groups containing cards from the categories [1,2,3,4], in some order. Similarly, the Image deck will yield groups containing cards from the categories [1,5,6,7], in some order.

The setup of the Association trick is therefore to order the two decks by category as described. The trick is best performed for one person, but can be done with a small group if they are able to agree on a choice together. Assuming one spectator, the performance of the Association trick then runs:

1. The performer welcomes the spectator, and asks for their name, checking that they would like to participate in a mind reading experiment. Using a pad of paper, the performer apparently notes down their name, using some pretence (e.g. 'I'll just note your name, sometimes it helps me connect with people if I write their name out, I don't know why...'). The pad of paper is put away.

2. The performer produces the two decks of cards, explaining that they contain Words and Images.

3. To show that the Word deck contains words, the performer deals eight cards *face up* on to the table, then quickly fans the remaining cards for the spectator to confirm that they are all word cards. The face up half of the deck is placed face down on the table, next to the other half, also face down.

4. The performer asks the spectator to shuffle the deck by pushing the two halves together, in a random fashion (or, if the spectator is comfortable handling cards,

to riffle shuffle the deck back together).

5. An identical procedure is performed with the Image deck.

6. The performer, emphasising that the decks are now randomised, deals four piles of four cards from each deck, face down onto the table, making eight piles in total, taking care to keep the piles of words and images clearly separated.

7. The performer asks the spectator to select one pile of words, and one pile of images.

8. The performer now states that the spectator's task is to quickly choose, from the eight cards in their hand, one word and one image that 'go really well together; a good, strong match', and to put the pair face up on the table. The intention is to put very mild psychological pressure on the spectator to make a quick, System 1, decision, rather than allowing their minds to have time to deploy System 2 type thinking, that may lead to idiosyncratic associations to be made between the cards.

9. The performer can appear interested in the selection at this point. The most likely choice that the spectator will have made is a word from category 1, with a matching image from category 1. All the other categories have been carefully chosen to be quite distinct from one another, though still related in some way to all the words and images in each deck.

10. The performer now retrieves the pad of paper from the beginning of the trick, and reveals that, in addition to the spectator's name, they also wrote a prediction about the cards they would choose. For example, if category 1 contains weather related images and words, a spectator may have chosen a picture of the sun, and the word 'Rain', and the performer could have written on the pad, about a spectator named Fred: 'Fred is interested in the weather today'.

At the conclusion of the trick, the spectator should feel that the performer has impossibly predicted a totally free choice they have made about some random words and images. The spectator themselves shuffled the cards, and made a free choice about the two piles of cards, and also the final pairing of cards.

What has actually happened is that the performer knows that, due to Gilbreath, at the end of the shuffling process the spectator will have a pile of images and words guaranteed to contain one word and one image from category 1 (and no more). The performer also knows in advance that the spectator should make a quick association between any of the four words and any of the four images from category 1, in preference to mixing any of the other categories, for example a word from category 3 with an image from category 6. Selecting suitably distinct categories is therefore critical. There is of course a chance that the spectator makes an unpredictable association, ruining the effect. We will later see how likely this is in practise.

6.1.3 Psychological factors [PSYCH]

As seen from the description of the Association trick, its effectiveness relies on the careful selection of categories. Crucially, these categories must be chosen to minimise conceptual overlap. For example, while Fruits and Vegetables are distinct categories, it is not impossible to imagine a spectator choosing a picture of an apple to match with the word 'Beetroot'. The key factor is to reduce the potential matches between categories, leaving one easy choice: category 1.

Table 6-A on page 116 outlines the various psychological factors, and relevant parameters, identified for the Association trick.

6.1.3.1 Theme: trademarks

Trademarks were chosen as a *theme* that the Association trick could be built around. A theme can be see as consisting of lists of classes; for example, the trademark theme consists of classes of brands ('Nike', 'Google', 'Coca-Cola', etc). In addition to automatically giving each image and word in each deck an overall similarity (loosely, companies),

Psychological factor	**Relevance**	**Parameters**
The trick relies on the spectator matching a word and an image from a set of choices.	Spectator.	1. The categories selected. 2. The words and images chosen for each category.
The spectator must be mildly pressured into deploying System 1 type thinking to make a choice.	Spectator and performer.	1. The script for the trick. 2. The skill level of the performer.

Table 6-A: Psychological factors in the Association card trick.

choosing trademarks as a theme capitalises on the work done by brand builders to cleanly separate the types of associative thoughts about each brand any given person may have. These thoughts fall into conceptual spaces crafted by the marketeers, from which distinct conceptual categories can be constructed.

From these categories - essentially pools of words and images - seven can be selected for use in the trick. Selecting seven categories that are conceptually far apart from one another minimises the chances that a spectator will make an association between a word and an image across categories, making it easier to stay within category 1, as wished for by the performer.

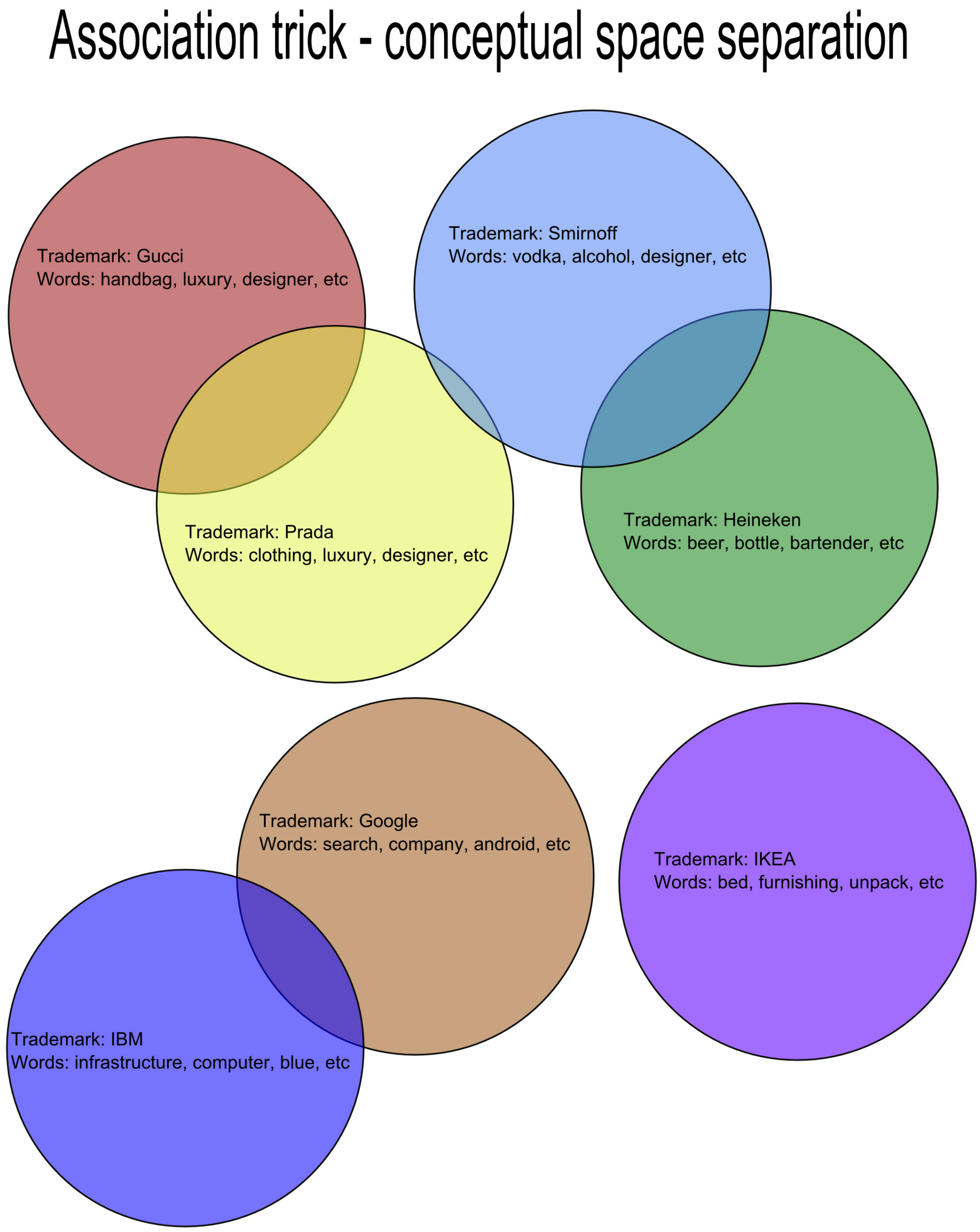
Using a theme gives each category an overall group to belong to (the theme itself), making the resulting categories, and therefore cards, less suspiciously separated when seen together. The overall grouping effect may be quite subtle, depending on the words and images used, but may be strong enough to give the decks of cards a credible feeling of cohesion.

6.1.3.2 Conceptual spacing

Trademarks are powerful cultural symbols that provide a pre-stratified set of conceptual spaces; they are very carefully constructed by advertisers and marketeers to carve out a niche area of mental space. There is commonality between the words and images that people think of when they see the trademarks, and these words and images minimally overlap with others that refer to different trademarks. Obviously, there is commonality between overarching groups, dependent on the market space that companies operate in. For example, the Ford trademark is likely to trigger similar general associations about vehicles as those triggered by the Mercedes trademark; however, there may be more specific associations that do not overlap; perhaps 'luxury' for the Mercedes, and 'affordable' for the Ford.

In addition to the words that are associated with each brand (via the trademark), there may also be common types of images (in addition to the trademark). This idea of conceptual space separation can be seen in figure 6.2 on page 118.

Figure 6.2 The words that people use to describe certain trademarks allow the conceptual space around each to be defined. Some naturally group together, some are cleanly separated. The Association trick relies on the separated groups.



6.1.3.3 Psychological data bank

In order to determine a general view of trademarks in this way, an online experiment was run, in which participants (N=87) were shown, in a random order, ten of the most famous one hundred trademarks, as determined by Millward Brown's BrandZ [221] statement for 2013, in their annual review of the most well known brands from around the world. All one hundred brands/trademarks were covered, but each participant saw only ten. They were asked, for each trademark, to write words about how the trademark made them feel, or any associations at all that they had about the trademark, and also to make a line drawing of anything that they associated with the brand. The gathered responses form a kind of data bank of words and images that people call to mind when asked about trademarks.

These words and images can be searched, categorised, and selected for deployment in decks of cards for use in the Association trick. The size of the data bank makes it a difficult task for a human designer to sift through and group the various trademarks into conceptually distinct categories, and to pick out meaningful words and images for each category. This task can be performed computationally.

6.1.4 Controlled problem domain [DOMAIN]

As noted, choosing the most conceptually distinct categories, and subsequently the words and images to populate each category, presents an interesting challenge for the trick designer.

The data bank gained from the online trademark association experiment provides a kind of document store. Each trademark has a body of text associated with it, along with a series of images. Viewed in this way, it is possible to construct the problem of identifying categories of words and images from this data bank as an information retrieval problem: analysing data to find a set of words (or images) that best represent that data.

The focus of the work undertaken for the Association trick is on the retrieval of words. It became apparent early on in the investigation phase that available techniques for machine comprehension of visual data are limited at best. It was also noted that images can be easily provided by an artist, or even a search engine, working from a word selected from a particular category.

The main problem is to group certain trademarks together into conceptual spaces based on the words used to describe them. However, the images gathered for the trademark theme provide a direct source for the trick designer to use, albeit one that is unsuitable for parsing by a computer.

6.1.4.1 Automated data gathering

It was noted that, in addition to the identification of distinct categories within the data, the gathering of the data itself could be automated by a computer, reducing the need for direct psychological experiments to be performed. The power of search engines such as Google can be harnessed to provide access to documents on the internet that belong to each class (e.g. trademarks/brands) of each theme. For example, for the trademark theme, it is possible to gather word data from the internet by performing a Google search, using each brand as the search term, along with a term explicitly defining the theme: e.g. 'Nike + brand'. Gathering and parsing the text that exists on the front page of the top ten pages returned by the search now provides the document store for analysis, in lieu of the direct data obtained in an experiment. As this is an entirely automatic process, it can be easily extended to different themes. For example, Countries (an example query: 'Greece + Country'), or musical Bands ('The Doors + Band').

Wherever the data is sourced, and multiple sources only strengthen the data set, the essential problem remains: given the relational data between each class in each theme, which of these classes group together to form natural conceptual groups, and what are

Element	**Function**	**Parameter**	**Relevance**	**Design**
Categories.	To be conceptually distinct, but within some overall theme.	1. Chosen theme. 2. Classes within theme, and grouping of classes.	Spectator.	Computer or human.
Words and images.	One set to suggest a stronger association between words and images than the other sets.	1. The words and images chosen.	Spectator.	Computer or human.

Table 6-B: Problem domain parameters for the Association trick.

the most meaningful words to be taken from the data to place in each group.

Table 6-B on page 121 outlines the various parameters identified in the analysis process of the Association trick, along with their potential for computational optimisation.

The identified problem can be solved by a human willing to sift through the data manually, making associations and classifications as necessary. However, while entirely feasible, this method does bias the generated trick towards the trick designer's own set of associations and prejudices about certain conceptual spaces and their content. Better, for a trick that is intended to be performed for random members of the public, that the mechanism deployed to choose the categories and words take into account more than one perspective.

6.1.5 Computational technique [AI]

As we have seen, the problem faced by the Association trick designer is to group sets of similar classes from the data (to avoid having similar classes in different groups), and also to select words that belong to these classes and groups that are significant and meaningful.

Before the developed algorithm for designing tricks of this type can be clearly stated, it is necessary to first describe the underlying techniques that were identified as being of use:

1. Information content.
2. Word similarity scoring. [222]
3. Okapi BM25 scoring. [223] [110]
4. Internet searches to provide document stores.

In the following sections these techniques are described, along with a section detailing the developed algorithm.

6.1.5.1 Information content

Information content (IC) is a basic metric used in computational natural language processing to convey how specific a concept a word describes. Higher values indicate that a more specific concept is represented by a certain word (for example 'pencil'); lower values indicate a more general concept (for example 'idea'). The IC of a word can be computed in the context of a body of text; the more frequently occurring words are seen as having lower IC scores. The IC scores are used here as a text pre-processing tool - to reduce the number of words in the document store by pruning words with low IC scores (for example 'the', 'and', etc.).

6.1.5.2 Word similarity

A key process in the Association trick algorithm is to compare two words for semantic similarity. For example, the word 'dog' is semantically similar to the word 'cat', but not to the word 'sky'. Providing a numerical measure of this kind of similarity is computationally difficult.

The WordNet system, originated by Miller [222], is a lexical database that describes hierarchical relationships between words, and is commonly used in natural language processing tasks. In WordNet, words are arranged into a tree structure that increases in specificity with depth; parent nodes subsume more specific instances - for example, the word ‘coin’ may be a parent to ‘penny’ and ‘pound’. WordNet provides a number of different similarity scoring mechanisms for two words, based on their parent nodes, and the depths of the respective words and parents. WordNet also provides sets of data describing synonyms for words.

Recently, work by Mikolov et al [224] [225] has produced a natural language processing tool called word2vec. This tool is an efficient implementation for computing vector representations of words, using continuous bag-of-words and skip-gram architectures. The tool operates on datasets, learning vector representations of words using neural networks, that can subsequently be manipulated in interesting, and somewhat surprising, ways. For example, trained on an appropriate dataset, word2vec can be used to calculate $V = vector('king') - vector('man') + vector('woman')$ returning a vector V that is close in vector space to $vector('queen')$. Google have published a pre-trained model, containing 300-dimensional vectors for 3 million words and phrases, trained on part of a Google News dataset of approximately 100 billion words. The model is able to provide good word similarity scores.

For the Association trick algorithm, being able to score words for semantic similarity enables comparison of meaning across categories, and between elements of the categories themselves.

6.1.5.3 Okapi BM25 scoring

Information retrieval is a field of computer science dedicated to finding specified data in, often large, datasets. Okapi BM25 is a ranking function, first developed at London’s City University in the 1980s and 1990s for use in search engines [223] [110], that scores documents for relevance to a search query; BM25 is the ranking function, Okapi the name of the information retrieval system that it was implemented in. 'BM' simply stands for 'Best Match', while '25' reflects the function's incremental development through BM11 and BM15 versions. Here, it is referred to as BM25.

BM25 is best stated as an equation (reproduced here from Russell [110]). The BM25 function takes a document and a query as an input and returns a score; higher scores reflect documents that are of more relevance to the query. The score is a linear weighted combination of scores for each of the words that make up the query. The weight of a query term is influenced by three elements:

1. How often a query term appears in a document; or, TF: term frequency.
2. The inverse document frequency of the term, or IDF. The inverse of how often a query term appears in all the documents in the store.
3. The length of the document.

Assuming N documents in the store, $TF(q_i, d_j)$ defines the count of the number of times word q_i appears in document d_j. A table of document frequency counts is also assumed, $DF(q_i)$, giving the number of documents that contain the word q_i. Then, for a document d_j and a query of words $q_{1:N}$, we have:

$$BM25(d_j, q_{1:N}) = \sum_{i=1}^{N} IDF(q_i).\frac{TF(q_i, d_j).(k+1)}{TF(q_i, d_j) + k.(1 - b + b.\frac{|d_j|}{L})} \tag{6.1}$$

where $|d_j|$ is the length, in words, of the document d_j. L is the average (mean) length of a document in the store. Two parameters are provided, k and b, that allow tuning of the function for use in different contexts. Typical values are $k = 2.0$ and $b = 0.75$. $IDF(q_i)$ is the inverse document frequency of word q_i:

$$IDF(q_i) = log\frac{N - DF(q_i) + 0.5}{DF(q_i) + 0.5} \tag{6.2}$$

Applying this function to each document in a document store, for a given query, will indicate the most relevant documents to the query. This is a key component of the Association trick algorithm, as it allows documents to be grouped into categories defined by relevance to certain queries. These categories can then be compared for conceptual similarity by performing word similarity scoring of the queries that define them.

6.1.5.4 Internet searches

As discussed, it is feasible to perform internet searches to gather crowd sourced data about certain themes, that can then either replace or augment a document store derived experimentally. For the trademark theme, the document store was generated using a combination of these two methods. Performing automated data gathering allows for the extension of the Association trick to other themes.

The basic process for gathering the data is to build internet search queries of the type: '[ThemeClass] + [Theme]', for example 'Nike + Trademark'. This search query can then be posted to a search engine. The top ten links returned by the search engine can then be visited, and all the text from each page appended to the document store for that particular document. The best words to use for [Theme] will vary; it was found by experimentation that using 'Brand' instead of 'Trademark' returned more useful results.

This method allows for the complete automation of the building of the document store for any theme.

6.1.5.5 Association trick algorithm

Often BM25 is used by search engines to retrieve relevant documents from a document store, given a particular query. We use it slightly differently here. Viewing the generated data bank of words for each class in each theme as the document store, where each document refers to a particular class (e.g. 'Nike', for the trademark theme), it is possible to generate BM25 scores for each document in the document store, for each word in a given dictionary.

These one word queries then have a set of ranked documents associated with them, which can be sorted with the highest scores at the top. Setting a threshold for the BM25 score, above which documents are seen as highly relevant to a particular query, allows the grouping of documents into classes defined by queries.

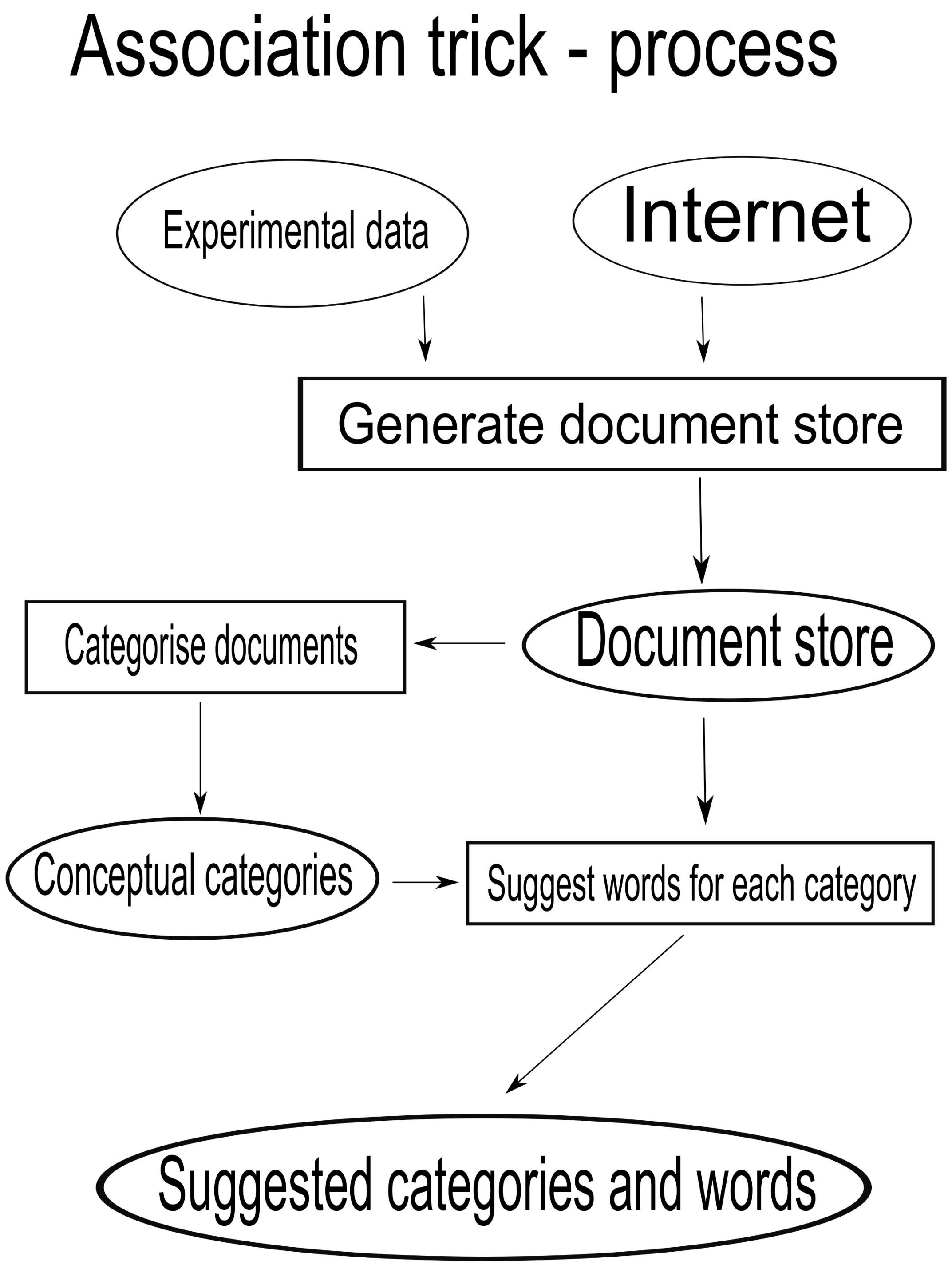
These scores also allow each document to be associated with multiple relevant queries. In this way, the document store can be categorised, and a set of words generated for each category. This provides the trick designer with a pre-computed set of words for use in the Association trick.

A companion set of images may be generated by taking a set of words for this purpose and feeding them into an image search engine, or passing them to an artist. In the case of the trademark theme, empirically sourced images are available directly from the document store.

The output of the algorithm is not a ready made trick. To generate the best trick, the trick designer is still required to sift through the suggested items, picking out a further refined set. We will see in later chapters how a computer is able to take on more and more responsibility for the generation of structures and data for direct use in tricks. This taking on of responsibility in the creative process, as we have seen in chapter 3, is the ongoing goal for much of the computational creativity field.

The algorithms for generating candidate data sets for use in the Association trick are shown in appendix A on page 264. A visual representation of the process is shown in 6.3 on page 127.

Figure 6.3 The computational and experimental process for suggesting categories and words for use in the Association trick. The document store is sourced experimentally and from the internet, before being processed and analysed for categories and words. If the theme is chosen well, the categories will naturally be conceptually far apart.



6.1.5.6 Association trick algorithm outputs

The algorithm outlined is able to output suggested sets of categories, and words associated with these categories, which the trick designer may use to construct an Association trick. The benefit of using this automated system is that rapid prototypes of themed tricks may be automatically produced, which the trick designer is then able to fine tune, comparing different themes to each other to find a suitable set from which to produce a full trick.

This type of computational assistance is of the kind widely used in many creative areas such as music composition, photographic editing, and computer aided design, where the machine is seen as a useful creative assistant, rather than as a full blown creative entity. The human operator is still very much key to the trick design process, though is now in possession of a powerful tool that can speed up the process, and potentially suggest ideas that may have been otherwise overlooked.

6.1.5.7 Association trick algorithm computation time

The main factor that determines how long the algorithm takes to run is the number of combinations of categories to evaluate for semantic separation, from the generated category list. To evaluate each combination, on a computer with an Intel Core i5 processor, takes approximately:

$$CategoryEvalTime = 0.01 \quad seconds \tag{6.3}$$

Allowing sets of seven categories (CategorySets) to be picked from the top 20 highest scoring categories (those with the most closely associated members: TopCategories), gives:

$$CategoryCombinations = \frac{TopCategories!}{(TopCategories - CategorySets)!(CategorySets!)} \tag{6.4}$$

$$CategoryCombinations = \frac{20!}{(20-7)!(7!)} = 77520 \tag{6.5}$$

, therefore, finding the set that are most conceptually distant takes approximately:

$$RunTime = CategoryEvalTime \times CategoryCombinations = 775.2 \quad seconds \tag{6.6}$$

Given more time, a wider range of categories may be used (e.g. picking seven category combinations from a list of 30).

6.1.5.8 Suggested words

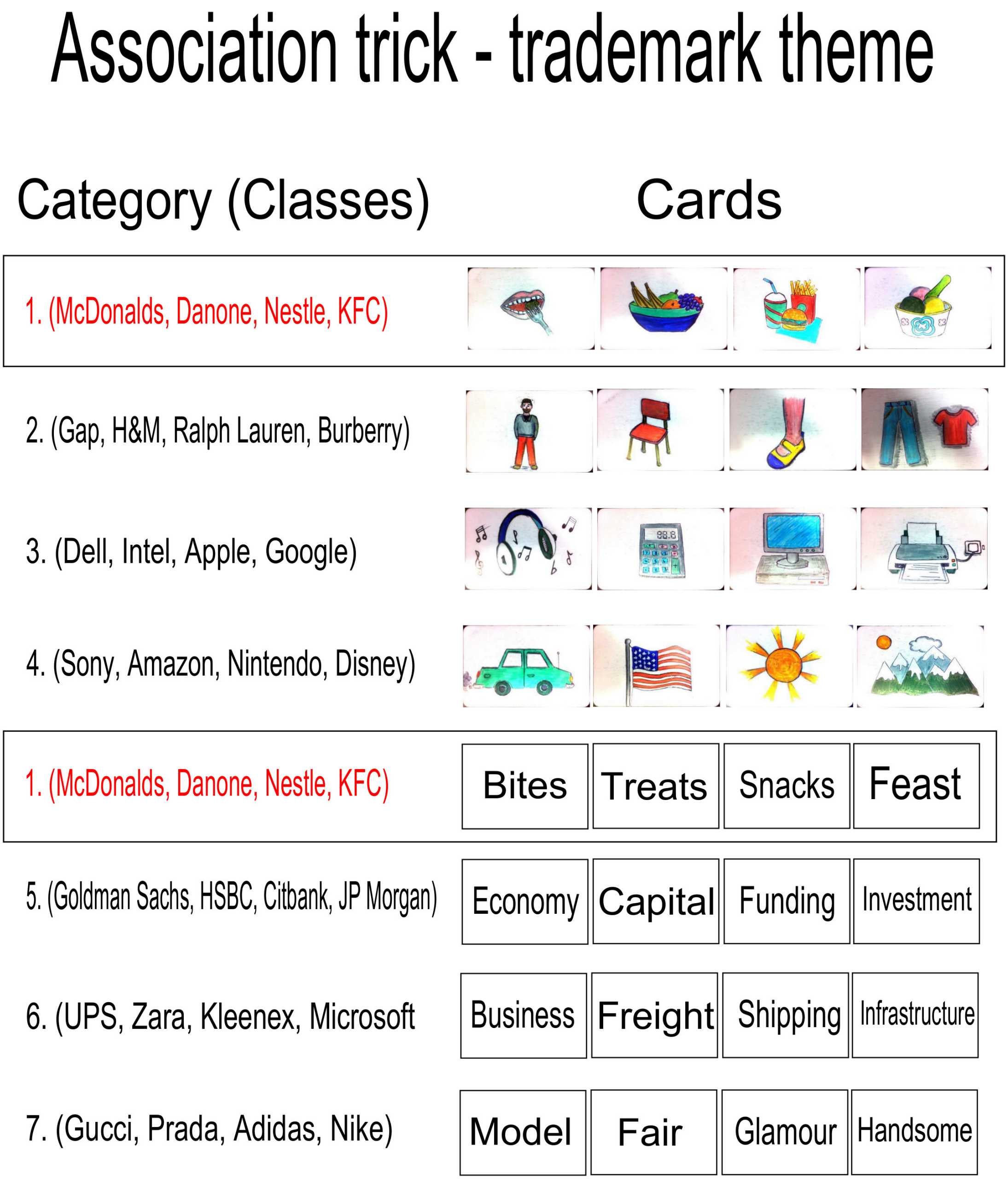
The algorithm was run for the trademark theme discussed, for 100 trademark classes, using a combination of the existing document store determined experimentally, and an internet sourced store. Seven categories were suggested from the top twenty identified categories. Words were manually selected (from the algorithmically suggested words) by the trick designer, and made up into a physical set of cards, that can be seen in figure 6.4 on page 131. The images were generated by an artist, using the experimentally determined document store of images for classes in the suggested categories, additionally informed by the suggested words from these classes.

The words suggested by the algorithm, selected by the trick designer, are more abstract than was anticipated, grouping classes of trademarks at quite high levels; some words are obviously directly related to certain members of the categories, e.g. ‘Shipping’ directly relates to ‘UPS’, a delivery company, while others only make sense on reflection: ‘Infrastructure’ relates to ‘Microsoft’ in the context of information technology infrastructure, and to ‘UPS’ in the context of a parcel delivery infrastructure. Some categories contain rather tenuously related classes and words; for example, ‘Kleenex’ and ‘Zara’ are both a ‘Business’, however, of course, all the classes in the trademark theme are businesses.

The algorithm is evidently far from perfect. The use of more sophisticated semantic similarity word scoring techniques would improve results, and a more extensive data gathering exercise may allow the algorithm more meaningful options for suggestions. However, some categories are surprisingly cleanly grouped: category 1 contains words that abstract various ideas around food that the trademarks it contains suggest, while the images provided from the empirically derived document store are strongly suggestive of the words, and vice versa; see figure 6.4 on page 131.

Something potentially quite nebulous about the group of trademarks in category 1 has been captured by the algorithm, that cleanly separates it from the other categories. While further pruning and improving of the decks of words and images could have been manually performed by a human designer, only suggestions made by the algorithm (and images in the document store) have been used to select from, in order to test the efficacy of the overall method.

Figure 6.4 Cards produced for use in the Association trick, with a Trademark theme. Category 1 defines the cards that the performer hopes the spectator will match.



6.1.5.9 Other themes

Two other themes were tackled by the algorithm, also with 100 classes per theme: countries (food), and well known musical bands. These were selected as possible themes that would exhibit similar properties to the trademark theme, in the sense that each individual class in each theme has a strong individual identity, and that these classes can naturally group together into categories - for example, European food may have similar semantic properties when discussed or written about, while popular musical bands are renowned for being viewed as parts of a 'scene' (a collection of similar bands).

The suggestions made by the algorithm were found to not be as useful as those for the trademark theme. This is likely due to the lack of a document store derived experimentally in a targeted way, directly gathering words and images that people associate with certain concepts (countries/food or bands). The document store built using internet searches is a vital component, allowing the algorithm to make more abstract associative connections across categories, though the more specific data from the experimental approach provides the key set of data that produces valuable suggestions from the algorithm.

6.1.6 Technology [TECH]

No special digital technology was used for the presentation of the Association trick. The focus here is the introduction of a computer system into the design process.

6.1.7 Evaluation [EVAL]

The Association trick was tested, with the trademark theme cards shown in figure 6.4 on page 131, at a science fair: the Big Bang 2013, at the NEC in Birmingham, UK. The ratings were compared to the ratings from those gathered for the classic magic tricks (N=96), reported in section 4.2.6.1 on page 77. Participants in the Association trick experiment (N=143) chose to sit down at a stall obviously marked as being about magic, and were thus likely self-selecting as being relatively interested in magic tricks. They were asked to take part in a science experiment that involved witnessing a trick, and then filling out the standard framework questionnaire. This set-up enabled a ruse on which the denouement of the trick relies: writing down the name of the participant ('I'll just make a note of your name, for the data...'). In fact, the words that were written down were of the form: '[Mike] looks hungry!', in anticipation of the participant selecting a word and image from category 1, which are all about food in some way.

This premise, that the participant will in fact choose an image and a word from category 1, is inherently risky. The free choice gives the trick some power; how, the spectator might wonder, can the performer predict a free choice? However, the associative machinery at work in a human mind does not always behave predictably. During testing at the science fair, the Association trick 'failed' 15 times out of 143. From these failures, it is interesting to note the word and image pairs that were selected by the participants: [Word: Model]-[Image: Clothes] (4), [Word: Model]-[Image: Car] (4), [Word: Handsome]-[Image: Clothes] (3), [Word: Glamour]-[Image: Clothes] (2), [Word: Funding]-[Image: Calculator] (2). In future iterations of the trick, these matches could be removed, either by modifying the algorithm to disallow certain terms, or by hand.

Successful performances of the Association trick received a mean rating score of 3.27 (out of 4), comparing favourably with the classic tricks. Participants in the Association trick experiment rated magic in general 3.50 (out of 4). As with the Princess trick, the scores are high, similarly reflecting the enthusiasm of the age group for magic (ages were not recorded, though ranged from approximately 8 to 16), and also the self-selecting nature of the participants. The key indicator, identified previously, is the difference between the score the trick receives, and the score the same group of participants give magic in general; for the Association trick it is 0.23, broadly in line with what is expected from a successful trick, as we have seen in previous chapters. Table 6-C on page 134 summarises the results.

Trick	**Mean enjoyment score reported for the trick**	**Mean enjoyment score reported for magic in general**	**Difference**
Princess card trick	3.58	3.79	0.21
Association trick	3.27	3.50	0.23

Table 6-C: Summary of enjoyment scores reported by groups viewing each trick. Lower Difference scores are better.

The qualitative view of the experience was recorded: the words chosen by the participants to reflect their experience of the trick. As previously, participants were asked to select as many words as they wished, from: Bored, Surprised, Obvious, Neutral, Impressed, Predictable, Amazed. The following word counts were received: Impressed (84), Surprised (40), Amazed (22), Predictable (7), Neutral (4), Obvious (1) and Bored (1).

Overall, it seems participants were mostly impressed by the performer's ability to predict their choice. They were also surprised, and sometimes amazed; this general reaction of being impressed is interesting; it points to the trick being received well as a performance, and to being somewhat inexplicable; however, it also highlights that even though the trick scored highly from a numerical perspective, it is perhaps not received as a genuinely magical experience most of the time, rather the participants enjoy the experience, and are impressed that the performer has second guessed them, but possibly have some notion that the relatively elaborate setup of the trick points the way to the method.

This overall qualitative impression is reinforced when looking at the explanations given by the participants for how the trick works (when it succeeded). Previously, with the Princess trick, explanations given were inadequate (unless the method was already known), and often took recourse to magical or impossible methods to describe the events witnessed. Here, more often than with the Princess trick, a good explanation for how the trick worked was provided (often along with a high enjoyment rating, and some positive qualitative word selection). Of the 128 participants, 16 provided an essentially correct trick method. From these 16, the mean average rating is 3.0 (out of 4); still a good score, though lower than the overall average. This is to be expected; working out the method reduces participant's enjoyment of magic tricks. The words used by the 16 were: Impressed (8), Surprised (6), Predictable (1), Neutral (1) and Obvious (1) (participants are free to select more than one word).

The most common suspicious moments reported were: writing at the beginning (20), shuffling of the cards (6), and the dealing of the cards (6). These provide good clues as to how to improve the presentation: a better mechanism may be required to make the prediction at the start of the trick, the spectators must always feel they have freely shuffled the cards (they have, in fact, but may in retrospect suspect they haven't), and the dealing of the cards could be handled by the spectator. Most commonly, participants did not report any suspicious moments.

6.1.8 Validation [VALID]

This particular trick has not been productised, though a saleable effect can easily be imagined, using the trademark themed cards described. Prior to making a trick for sale, it would likely be fruitful for a designer to go through another iteration step, using the results of the real world test to further optimise the categories, words, and images, to minimise the chances of failure.

6.1.9 Conclusions from the Association trick

In this section, the Association trick has been described, and the design process followed has been detailed. The framework for designing and optimising magic tricks has been applied, with the introduction for the first time of a computational process, intended to assist the trick designer. This has highlighted issues around the complexity of configuring computers to work with sophisticated human constructs such as language, visual imagery, and mental associations. The computer has been shown to be a useful time saving tool, and to have value as a kind of suggestion device for a particular creative task. Natural language is difficult even for humans to be creative with, though here a method has been arrived at that allows the human designer overall creative control with the added benefit of being able to rely on a computational aggregator and data sourcing mechanism.

The Association trick is still very much a result of a human creative act, though a computer now stands in as a proxy for some of the process. Part of the optimisation of the trick, the conceptual separation and word/image selection, is assisted by a machine, resulting in a trick that was generally well received in the real world. The testing of the trick has pointed to weaknesses in the overall presentation. While the suggestions from the computer are often sub-optimal, and need to be filtered by a human, it is notable that the modular nature of the framework allows for more sophisticated algorithms to be imagined and plugged in at each stage of the trick's design.

The process discussed in this section highlights the inherent difficulties involved in designing tricks computationally; computers blindly crunch numbers, and have no sense of what works for real people; this capacity to deal with human factors in a trick, such as natural language, must be built in to the system by the trick designer. The poor results from the additional themes (food/country and musical bands) indicate a weakness in using a document store populated exclusively using the automated method described. Relying on empirically sourced data to guide the algorithms has been shown to be essential; without the additional document store items sourced directly from people's associative reactions to classes within a theme, the Association trick algorithm struggles to categorise classes from themes in meaningful, useful ways, though is still able to make interesting suggestions about words associated to each class in the theme.

6.2 Crystal Ball; a mind reading word association trick

6.2.1 Background

In the previous section, a new trick was designed and developed using the framework, introducing a computational aid to both categorise conceptual classes, and to make suggestions of words useful to the trick designer. While the produced trick was a success during the testing phase, the creation process relied heavily on the human trick designer to filter the suggestions made by the algorithm. However, useful observations were made about how to implement natural language processing systems in trick design contexts.

One benefit of using a computer to assist with the design of the Association trick was the automatic suggestions about the way words could be associated with concepts in the mind of a spectator. This was achieved by generating a document store of information relevant to particular classes within certain themes. While the document stores that were built automatically using internet searches provided less coherent categorisations of the data, the suggestions of words made for each class were more relevant.

Natural language processing is a difficult domain for a computer. However, considering the algorithms, detailed above, for word suggestions, and noting existing magic tricks that rely on words for their operation, a new trick, based on branching anagrams (BAs), was formulated, requiring an increase in the level of responsibility of the computer in the design process.

6.2.1.1 Branching anagrams

Branching anagrams, also commonly referred to as progressive anagrams, appear to have been invented by Stanley Collins in 1920 [226]. They are a type of mind reading effect that allows a performer to divine some piece of information secretly held by a spectator, in some particular domain; a classic example is the signs of the Zodiac. Most people know their star sign (regardless of their opinion of its relevance to their life); they also know that it is unlikely for a performer they have never met before to know their date of birth. A BA is a construct that allows a performer to ask a number of questions related to the letters that appear in the names of the list of items in the particular domain. Having asked a small number of questions, the performer is able to name the spectator's chosen item from the domain. The key to the effect is to ask innocuous sounding questions, or to instead make statements of fact that may be refuted, but then explained away.

A good example of a BA is provided by Kevin Dunn [227]:

> What frisky anxious
> monster doesn't consider
> nearsighted maidens.

This Haiku appears innocent enough. However, closer inspection reveals a simple method to recover any of the words a spectator may secretly choose from the Haiku. The method hinges on a mnemonic key, arrived at by reversing the final word 'maidens', to give 'snediam'. Based on the mnemonic, a series of questions can be asked, each question determining whether the particular word chosen by a spectator contains a certain letter. Starting with the first letter of 'snediam', 's', it can be seen that the first word of the Haiku, 'What', does not contain an 's', but all the remaining words do. Proceeding through 'snediam' letter by letter, and simultaneously advancing one word at a time through the Haiku, allows the performer to know the spectator's word: when the current word does not contain the current letter. The presentation of this type of effect is critical, as simply asking questions of the form 'does the word you are thinking of contain the letter S?', will inevitably lead the spectator to the underlying method.

Using the final word of the Haiku as the mnemonic key to retrieving the correct word is an ingenious idea, though does limit the trick designer to sets of words that have this property. Kevin Dunn's website provides a computational tool to generate possible words for use in BAs, taking the final word as an input. This generates a long list of words to choose from; very useful for a trick designer.

After some consideration of BAs, an improved method of creating and performing them suggests itself: using a computational assistant to aid with the combinatorial and natural language problems inherent in BA design, and also to provide a visually appealing presentational tool, able to recall the underlying letter map itself, removing the need for a mnemonic word.

6.2.2 The trick [MAGIC]

In addition to Dunn's word generator, there are other tools available to the working magician looking to produce a BA. Panagram [228] is widely used to create the underlying letter/word structure required; it takes as its input the list of words of interest (e.g. the signs of the Zodiac) and returns a suggested path of letters to follow. Panagram appears to work by analysing the letter frequencies in the list of provided words, and calculates a quick route through a tree of possibilities.

There are also commercially available tricks that detail both the structure of the words, letters, and questions to use, and provide suggestions for how to explain away errors during questioning. Sign Language, an effect developed by Doug Dyment [229], is a product that describes a detailed approach to unveiling a spectator's Zodiac sign, based on an underlying BA. The star sign of a spectator is divined by repeatedly stating facts, and explaining away errors; for example, a performer may state to the spectator something of the form: 'there's an I...no?...yes...two eyes staring back at me, quite aggressively...it's a Bull...your sign is Taurus'. This explaining away of the 'no' response from the spectator is critical in this type of effect, as it allows the performer to build the illusion that everything they state during the purported mind reading process is correct; a failure would seem suspicious, undermining credibility.

During presentation of these types of trick it is important that the performer does not obviously use any kind of memory aid, such as a chart describing the sequence of letters to enquire about. A different mechanism of presenting this type of effect was identified, that would allow a performer to carry around many different versions of the effect without having to memorise them all: a mobile phone. The phone would operate as a kind of memory bank, and presentational device, secretly operated by the performer. The screen of the device would play the role of a kind of crystal ball; peering into the screen would appear to cause letters from the spectator's freely chosen word to emerge, while erroneously presented letters would also be explained away, culminating in the word itself being revealed.

6.2.3 Psychological factors [PSYCH]

The crucial psychological factors in the newly developed trick, **Crystal Ball**, in which a mobile phone takes on the supposed mind reading abilities, secretly controlled by a performer, are:

- The spectator must be unable to easily determine the underlying structure of the letter/word combinations.
- When an error of divination occurs, it is convincingly explained away with a word (or phrase) that is strongly associated with the word that the spectator is thinking of.

The number of errors that occur during the mind reading process must be minimised: the ideal effect is for the mobile phone to simply spell out the word that the spectator is thinking of; this may be possible for one of the words from the theme (e.g. Zodiac signs) list, however, other routes to an answer will require mistakes to be made, to branch off to the correct answer.

Table 6-D on page 141 outlines the various psychological factors, and relevant parameters, identified for the Crystal Ball trick.

Psychological factor	**Relevance**	**Parameters**
The number of questions/statements required by the performer to divine the correct word affects the magical experience for the spectator.	Spectator and performer.	1. The number and choice of words in the list. 2. The number of letters used to define the questions/statements.
The errors that occur during letter presentation must be strongly explained.	Spectator and performer.	1. The associative words selected for each error. 2. The presentational skill of the performer.

Table 6-D: Psychological factors in the Crystal Ball trick.

6.2.4 Controlled problem domain [DOMAIN]

The branching anagrams that are required for the Crystal Ball trick can essentially be viewed as tree structures [230], with branching nodes defined by a letter, and a group of words that either contain that letter, or do not. Therefore, each node has two children: a 'yes' node, and a 'no' node. All nodes that are visited after taking a 'yes' branch will contain words that contain the letter at the branching point. All nodes that are visited after taking a 'no' branch will contain words that do not contain the letter at the branching point

The route through the tree gradually prunes away possibilities for the word thought of by the spectator. Leaf nodes in these trees are the end points of the questioning process, that contain individual words; once reached, the performer knows the word the spectator is thinking of. The overall number of questions (branching points) and mistakes ('no' nodes) needs to be minimised. Once a candidate tree has been constructed, its quality as a solution can be evaluated, based on metrics drawn from the psychological factors that affect the magical impact of the effect.

As with the Association trick, it is natural for BA tricks to be themed: soccer teams at the 2014 World Cup in Brazil, and subjects studied in schools, were selected as good themes to develop for this work. This themed basis for the trick allows the performer to ask a simple question that makes sense for a spectator (for example, 'what is/was

Element	**Function**	**Parameter**	**Relevance**	**Design**
Tree structure.	To provide a route of questions, through to the answer.	1. Chosen theme. 2. Classes (words) within theme.	Spectator and performer.	Computer or human.
Explanatory words.	To provide an explanation at a tree node where a 'no' response is given by the spectator.	1. The explanatory word/phrase chosen.	Spectator.	Computer or human.

Table 6-E: Problem domain parameters for the Crystal Ball trick.

your favourite subject at school?'), rather than presenting a list of random words to choose from. The defined list of words must be presented to the spectator, to avoid them choosing an item outside of the domain.

An ideal route through the words requires just one 'no' response from a spectator to determine the selected word, as with the Haiku example above. While this approach yields a simple performance method, it will not always produce an explainable error, and further not all (larger) domains are amenable to this solution. For example, if, during a performance, a spectator secretly selects the word 'What' from the Haiku, the first letter enquired about by the performer is 's', producing a 'no' response. It is difficult to imagine a sensible explanation for the performer to deploy to explain this mistake, though not impossible, perhaps: 'ah, I see now...it's the phrase So What...the S confused me...you're thinking of the word What'. This justification may be broadly 'convincing' to the less cynical spectator (i.e. the performer may get away with it) but is obviously weaker than would be desirable. The link between the error letter and the word/phrase that explains it away is critical. An associative link must be made for each mistake in the tree. As we have seen from the Association trick above, this type of associative suggestion can be generated and scored algorithmically.

Table 6-E on page 142 outlines the various parameters identified in the analysis process of the Crystal Ball trick, along with their potential for computational optimisation.

6.2.5 Computational technique [AI]

A tree structure, built from a list of words, defined by a sequence of enquiry letters, may be constructed by repeatedly analysing the frequency of letters making up the words in the list, and structuring the word list appropriately. This straightforward approach allows for the generation of an optimal tree for a given group of words, if the only consideration is how many questions need to be asked to resolve each word, minimising negative responses. This appears to be the underlying approach taken by Panagram, and other similar BA generators.

The problem is viewed here in a different way; the algorithm is also tasked with making suggestions for explanations for each error in the tree. It may be that a tree that is sub-optimal, in terms of numbers of errors, may be more highly prized by a trick designer, as each mistake is more easily explained. The problem therefore becomes combinatorial, as there are many different trees that can be built from the same list of words. The problem also requires the application of natural language processing tools, similar in nature to those described in the previous section, in order to distinguish the quality of trees based on psychological measures.

6.2.5.1 Processing and evaluating tree structures

The developed algorithm constructs many branching trees from initial seed letters, used at the root node (one letter per tree). The letter defines child nodes that branch from the root; one child node contains a set of words that feature the letter (a 'yes' node), another a set of words that do not feature the letter (a 'no' node). This process is subsequently repeated for each of the resultant child nodes; however, for the child nodes, each letter in the alphabet is examined, with only those letters generating the highest numbers of words in the 'yes' nodes retained at that level in the tree. Each level may contain multiple options for letters, as the number of words in the associated 'yes' node may be equal for each. The processing completes when only one word remains at a node (a leaf), or the search fails (all letters in the alphabet have been examined).

These trees, with optional routes through to the leaf nodes, can subsequently be scored and pruned on the quality of the ‘no’ nodes. The ‘no’ nodes are evaluated by a process whereby a kind of knowledge map is used to generate suggestions for explanatory words (or phrases) for the words contained at the nodes. The explanatory word’s first letter will be the same as the letter at the node.

6.2.5.2 The knowledge map

The knowledge map is a structure in which each element of a theme’s class list is assigned a bank of highly relevant words. This can be achieved using a document store, populated via the automated online method outlined in the previous section for the Association trick. From this document store, it is possible to retrieve words that are strongly associated with each class in the theme. These words form the *knowledge* about each class. For example, the subject ‘physics’ may have the words ‘atom’, ‘particle’, and ‘momentum’ associated with it, amongst others.

For each node in the tree where an error occurs, i.e. where the performer states that they *see* a particular letter which does not in fact occur in the spectator’s chosen word, there will be a number of associated words (one, or many) at the ‘no’ node, all of which are possibly the spectator’s chosen word; they must all be explainable in the same way, i.e. with the same suggested explanatory word (or phrase); therefore, if a single word, or short phrase, that starts with the erroneously presented letter can be given as an explanation that is strongly associated with all the items at the node, it should be accepted by the spectator.

6.2.5.3 Tree quality

The quality of a tree can be seen as a combination of its numerical properties - how many questions are required to retrieve each word from the item list, and how many erroneous nodes occur - and a score defining the strength of the explanations found in the knowledge map.

A ‘yes’ node is seen as having zero cost, as it is a successful guess by the performer, while a ‘no’ node is seen to have an associated cost, based on the quality of the explanatory word (or phrase) associated with it.

Thus, a tree with only a few ‘no’ nodes may in fact have a high cost, if there is no way of explaining the items at those nodes, or if the explanations are particularly weak. This is highly relevant to a performer building this kind of trick. While the final trick can always be refined manually, it is suggested that this computational process can save a lot of time, and highlight previously missed connections and explanations.

The technique developed to create trees, from themed lists of words, is detailed in the algorithms in appendix B on page 268.

Applying the algorithms to two themes - soccer teams at the 2014 World Cup in Brazil, and subjects studied at school - produced the tree structures detailed in figures 6.5 on page 146, and 6.6 on page 147. No manual refinement has been performed on these trees. The knowledge map was generated using the automated method detailed in the Association trick section, then augmented by a human to clarify and expand certain words and phrases.

6.2.5.4 Crystal Ball trick algorithm outputs

The tree representing the trick with a school subject theme is slightly more complex than that describing the soccer teams, as there are 18 subjects, but only 16 teams. However,

Figure 6.5 The tree structure generated by the system for use in the Crystal Ball trick with a theme of favourite subject at school. The explanation words were suggested by the system, using a knowledge map, to encapsulate something meaningful about the word(s) at that particular node.

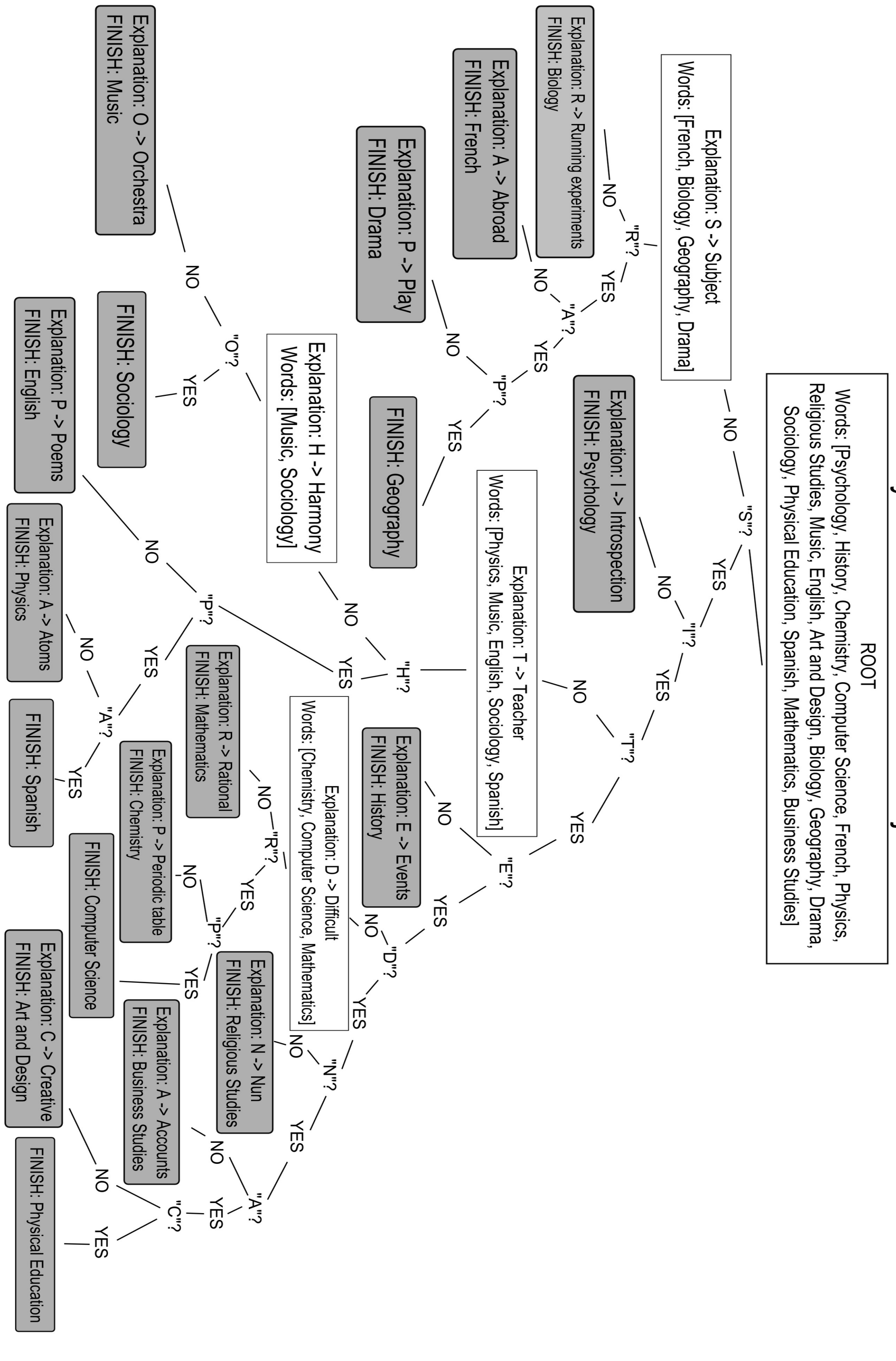
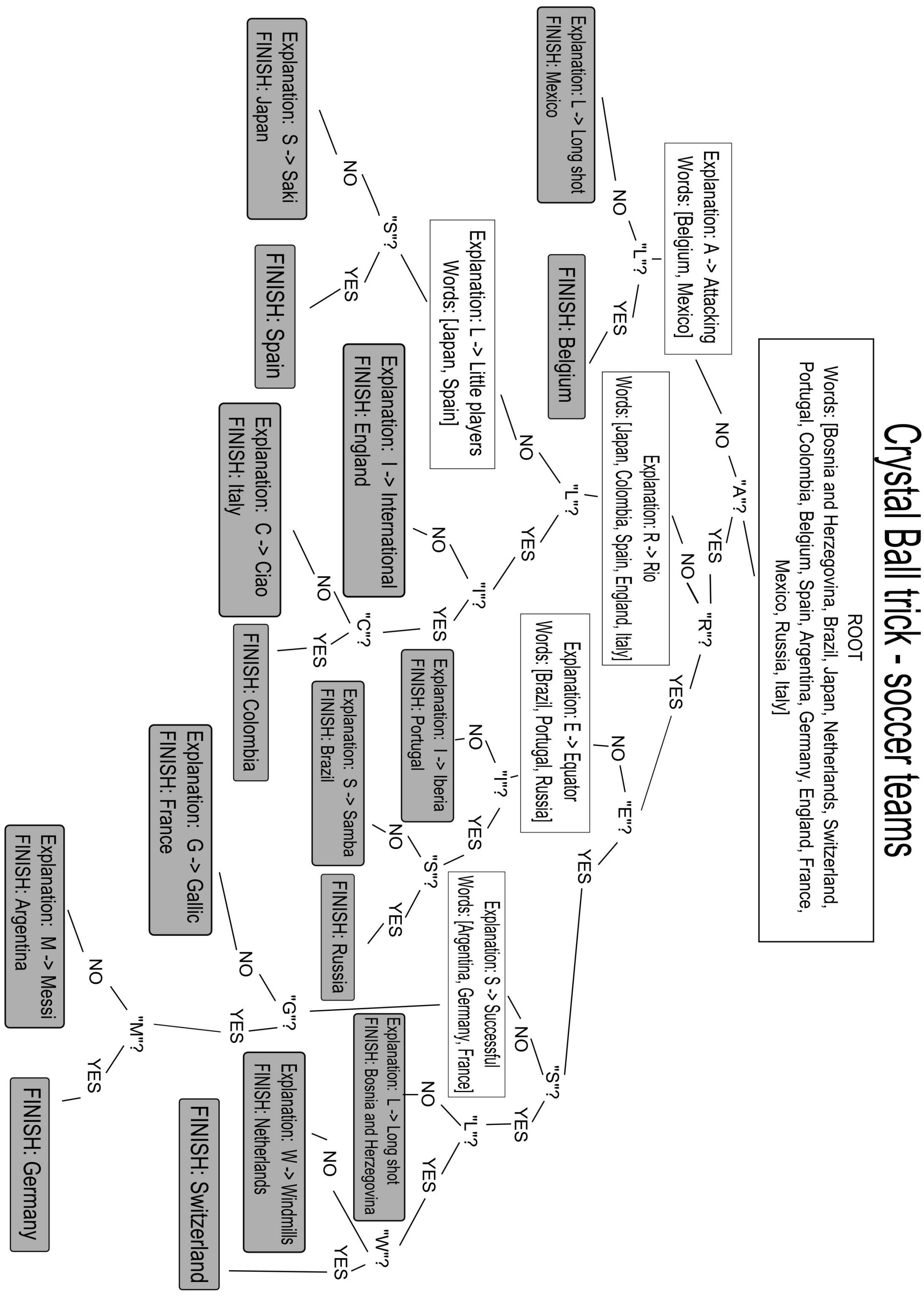


Figure 6.6 The tree structure generated by the system for use in the Crystal Ball trick with a theme of soccer teams at the World Cup in Brazil, 2014. The explanation words were suggested by the system, using a knowledge map, to encapsulate something meaningful about the word(s) at that particular node.



each tree has the same worse case scenario of three 'no' responses from a spectator to reach an answer (Japan, and Music respectively).

The key element that indicates the quality of the solutions is the explanatory words suggested at each 'no' node. Some are low quality, for example at the 'no' leaf node where England is the answer, the best suggested word from the system is 'International'. This, while providing some kind of plausible meaning, will require the performer to work fairly hard to make the spectator feel that a remarkable event has occurred.

Similarly, the first 'no' node in the school subject tree tries to encapsulate a number of disparate words with the word 'Subject'; fortunately, as this is the first node in the process, it would be relatively easy for a performer to explain this away during performance ('an S...no?...yes...simply Subject...it's a weak signal at this point...'). Likewise, 'Teacher', further down the tree is rather too general, but can easily be presented as 'favourite teacher from school' - often, someone's favourite subject at school is taught by their favourite teacher.

Some of the suggested explanatory words are more useful; the two nodes in the soccer tree immediately preceding the answer Japan are convincing: 'Little players' and 'Saki' seem specifically about Japan. Similarly the suggested word 'Difficult' that encapsulates three distinct school subjects, that are in fact commonly thought of as hard (Mathematics, Chemistry, and Computer Science), is a good suggestion from the system.

It should be noted that there are other trees available for selection by the algorithm, that have only a maximum of two 'no' responses to reach an answer, that were passed over in favour of the presented trees, due to the higher quality of suggested explanatory words. It is not a trivial task for a human to combine and recombine trees, while also thinking of explanations for each node. The method presented here allows the rapid generation of good quality trees on any theme, which can, if necessary, be further refined.

6.2.5.5 Crystal Ball trick algorithm computation time

Theoretically, with a particular set of words, there can be up to 26 factorial (approximately 4×10^{26}) different trees that can be constructed and evaluated. However, practically, this number will be greatly reduced, as not all sets of words use all the letters of the alphabet, and not all branches of each tree leads to a viable solution. There are, however, a large number of trees to evaluate, for a human designer. Even constructing a few hundred trees would be inordinately time consuming, particularly when tasked with suggesting explanatory words for each 'no' node. The developed algorithm runs, excluding the generation of the knowledge map, in approximately 30 seconds, on a PC with an Intel Core i5 processor.

The computation time can rise significantly if a theme is chosen that contains a larger number of classes than those to be used in the trick. For example, if the Trademark theme from the previous section, containing 100 classes, were to be used, it would be a clunky and unwieldy trick without selecting a subset of perhaps 16 classes to present to the spectator during performance. For a full evaluation of the possibilities, this would require evaluating all combinations of 16 from the 100 classes (taking approximately 30 seconds per combination, from approximately $10^{1}8$ combinations). This is not computationally feasible using a simple exhaustive search, and is largely unnecessary. The trick designer may simply pre-select 16 classes.

6.2.6 Technology [TECH]

The algorithmically generated trees are the underlying structure of the Crystal Ball trick. However, the trick must also be performed in a convincing way. In order to both further investigate the potential for integrating computational technologies into magic performances, and to test the trees generated by the developed algorithm, a mobile phone application was produced, capable of presenting the trick using any particular generated tree.

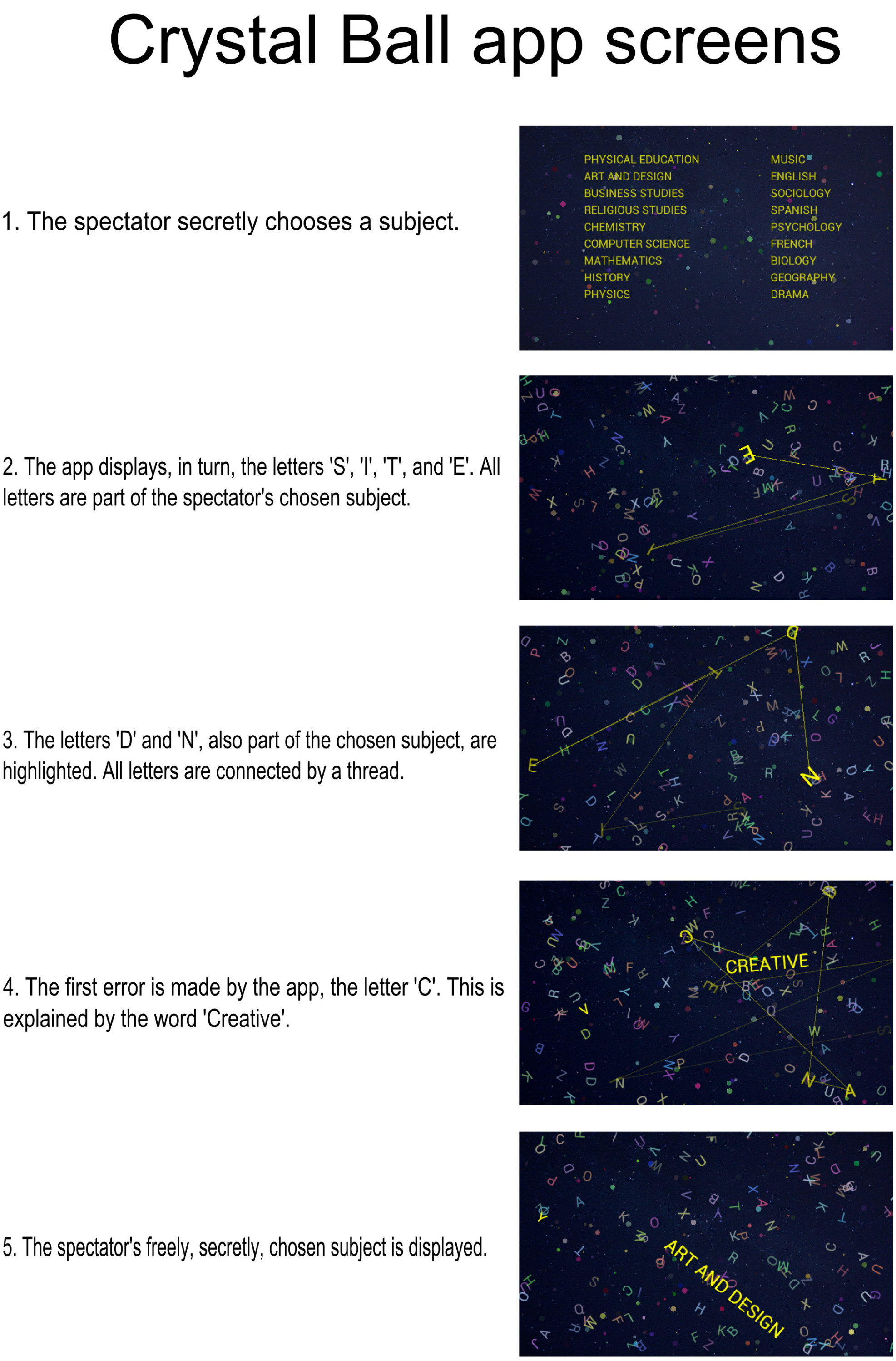
The premise of the app was to present the phone's screen as a kind of crystal ball, into which a spectator would peer. The screen shows letters emerging and being highlighted from a kind of letter soup bouncing around the screen; ideally the highlighted letters are those that are contained in the word the spectator had freely selected from an initially presented list. As each letter appears, it is connected to the previously identified letters by a straight line, a kind of thread, that moves with the letters. The performer subtly manipulates the phone, to indicate to the software whether the spectator has indicated a 'yes' or 'no' response to each new letter. When a 'no' is arrived at, the word or phrase that justifies the 'no' appears instead of a letter. This builds a visual, animated, picture of the ongoing connections that the app is divining from the spectator - as soon as a leaf node is arrived at, the screen displays the spectator's chosen word, and the trick ends.

The mechanism allowing the performer to pass yes/no information to the screen is based on the proximity sensor technology built into all modern smartphones, that is designed to turn the screen off when the phone senses that it is being held up to someone's ear; the sensor's capabilities can be accessed programmatically, and used for other purposes.

Here, the phone is configured to sense when the performer passes their hand/finger/thumb over an area of the phone. As the letter that is being currently enquired about bounces around the screen, the performer waits for it to be in a particular region before activating the sensor; the border of the screen indicates a 'no' response, whilst anywhere in the central region of the screen indicates a 'yes'. This allows a performer, with some practise, to be able to secretly pass information to the software, essentially in plain sight of the spectator.

See figure 6.7 on page 151 for a series of screenshots of the app in progress.

Figure 6.7 The Crystal Ball app in operation. The spectator first chooses from the list of theme classes (here, school subjects). The app, secretly prompted with 'yes'/'no' responses from the performer, then proceeds to highlight letters that appear in the spectator's freely and secretly chosen subject. On encountering a 'no', the letter 'C', the word 'Creative' is displayed, immediately before the spectator's choice is successfully revealed: 'Art and Design'.



6.2.7 Evaluation [EVAL]

The Crystal Ball trick, configured with the school subjects theme, was tested with random members of the public at a science fair: The Big Bang 2014 at Westminster College. The ratings were compared to the ratings from those gathered for the classic magic tricks (N=96), reported in section 4.2.6.1 on page 77. Participants in the Crystal Ball trick experiment (N=40) chose to sit down at a stall obviously marked as being about magic, and were thus likely self-selecting in terms of being relatively interested in magic tricks. They were asked to take part in a magic trick, and then asked to fill in the standard framework questionnaire.

Performances of the Crystal Ball trick received a mean rating score of 3.50 (out of 4), comparing favourably with the scores reported for the classic tricks. Participants in the Crystal Ball trick experiment rated magic in general 3.52 (out of 4). As with the Princess and Association tricks, the scores are high, similarly reflecting the enthusiasm of the age group for magic (ages were not recorded, though ranged from approximately 8 to 16), and also the self selecting nature of the participants. The key indicator, identified previously, is the difference between the score the trick receives, and the score the same group of participants give magic in general; for the Crystal Ball trick the difference is 0.02; as we have seen in previous chapters, this is a very good score. Table 6-F on page 152 summarises the results.

Trick	**Mean enjoyment score reported for the trick**	**Mean enjoyment score reported for magic in general**	**Difference**
Princess card trick	3.58	3.79	0.21
Association trick	3.27	3.50	0.23
Crystal Ball trick	3.50	3.52	0.02

Table 6-F: Summary of enjoyment scores reported by groups viewing each trick. Lower Difference scores are better.

The alternative qualitative view of the experience was recorded: the words chosen by the participants to reflect their experience of the trick. As previously, participants were asked to select as many words as they wished, from: Bored, Surprised, Obvious, Neutral, Impressed, Predictable, Amazed. The following word counts were received: Impressed (21), Surprised (13), Amazed (17), Predictable (2), Neutral (2), and Obvious (3).

Overall, it seems participants were mostly impressed, surprised and amazed by the performer's/phone's ability to divine their choice. The Crystal Ball trick received both a higher numerical score, and a higher ratio of amazed and surprised reactions than the Association trick from the previous section. This may be due to the method being more successfully hidden by use of the mobile phone. In fact, the very presence of the phone as the main presentational device may have contributed to the good reception. The nature of the trick, dealing with language and associations, is a very human one; it may be that the ability of a phone to perform this kind of apparent mind reading is more magical to an audience than if a human can do it alone.

Two participants had a very good theory for how the trick works, indicating that the phone used a pre-selected list and that the performer was passing information to the app about the letters that appeared on screen.

Seven participants mentioned that the performer's thumbs were probably involved (subtle thumb movements were used to trigger the phone's proximity sensor, indicating 'yes'/'no' responses). It is difficult to know if this was due to a poor performance, or a particularly astute spectator. However, it does underline the importance of performance for this trick. The phone alone is not sufficient technology for the trick to be a success. However, three participants thought that it in fact it was performing the trick alone, reporting that the phone was listening to them talk as the trick progressed and subsequently working out their favourite subject.

Two participants explained the method as the phone performing mind reading, though presumably this was written as a last resort, rather than a genuine belief (these participants were informed after filling out the questionnaire that the phone was not in fact reading their mind, but that the whole effect was a trick of some kind).

One participant thought that the performer observed the spectator at the beginning of the trick and noted which item from the list of choices they looked at.

Five participants mentioned, as a suspicious event, the moment that an explanatory word appeared on the screen. This is not necessarily a negative report, as each rated the trick highly. The explanatory words/phrases always appear immediately before the spectator's choice is revealed. This report of a suspicious event may therefore be a way of expressing that the explanatory event functioned as a kind of suspense building precursor to the reveal. The explanatory words, instead of weakening the effect, may in fact strengthen it.

Two participants mentioned that it was suspicious that there were so many questions being asked by the performer. Again, it is difficult to know if this is due to a bad performance, or a weakness in the structure of the trick.

Seven participants reported being suspicious of the letters as they appeared, and that they were connected on screen.

6.2.8 Validation [VALID]

The trick was developed into a product (named Crystal Ball) and released for sale on the Google Play store for mobile phones running the Android operating system, and marketed via the reputable magic shop Davenports, in London, UK. Davenports advertised the app on their own website. This is direct evidence that the framework developed trick is suitable for magicians, as it is assumed that Davenports would be unwilling to carry the product on their website if they thought that it would reflect negatively on their reputation as purveyor's of quality magic-based items.

The app, as a commercial product, is quite flexible in the sense that it can easily be updated with new versions of the trick - new themes can be worked on and remotely deployed to each phone running the app, via an automated update. This is a good way, from a commercial perspective, to keep users interested in the product.

Further, it shows that the framework is capable of generating products that are of interest to people other than the builder of the framework. Sales of the trick, relatively low at the time of writing (35 copies sold), indicate that people are willing to spend money on the product (which retails at £0.69, a price comparable both to other general apps, and to other magic related products).

6.2.9 Conclusions from the Crystal Ball trick

In this section, the design and optimisation of the Crystal Ball trick has been described. The framework has been applied, incorporating, in some way, its full capabilities for the first time: a computer has been used both in the creation, and presentation, of the trick. Work done on natural language processing for the creation of the Association trick has been integrated into a combinatorial algorithm that outputs tree structures, optimised using psychological and numerical measures. This algorithm quickly performs tasks that would be time consuming for a human designer, additionally making useful natural language suggestions about associations that can be deployed during the trick to enhance the general illusion of mind reading.

Both the Association and Crystal Ball tricks are the result of a mixture of human and computer design processes, however for the Crystal Ball trick the computer takes on more responsibility for generating the underlying structures used in the final effect.

This automated generation of more of the fundamental elements of the trick pushes the computer further in the direction of the computationally creative entity discussed previously; however, it should be noted that the human agent remains critical here, both in the final selection of certain aspects of the knowledge map, and during the performance of the trick.

The developed algorithm is able to deal with much of the combinatorial complexity inherent in the building of the tree structures used, though falls short of being able to successfully process themes with larger numbers of classes - in this scenario, a human is still required to pre-select classes from a theme, ready for the computer to process; this ability to perform higher level decision making in larger problem spaces requires more sophisticated AI techniques to be introduced into the process, relieving the human agent of more and more of their design responsibilities.

6.3 Summary

Two new language based tricks have been developed and evaluated using the presented framework, based on psychological theories and concrete experimental data about the strength of associations between words, images, and concepts in people's minds. The role of computational aids in the design process has been introduced. It has been argued that data gleaned from the internet can stand in as crowd sourced representations of psychological stances towards certain concepts and objects. Further demonstration of the potential of mobile phones to function as presentation tools for magicians has been provided; such devices have also been shown to be capable of aiding a magician during performance by operating as an unseen memory bank. A partially hidden input method to the phone for the magician has been developed. The next chapter will explore the possibilities afforded by expanding the role of a computer in the design process, by using more sophisticated computational techniques.

Chapter 7

Exploiting computational techniques in the magic trick design process

In Chapter 6, two new tricks were developed using the framework. For each trick, a computational system lay at the core of the design process, but a human designer was still doing a lot of the work. In this chapter, a more sophisticated computational tool, a Genetic Algorithm (GA), is introduced into the framework, more fully automating the trick design process. This system uses constraints derived from experimental data gathered about the vertical-horizontal illusion; a particular feature of human perceptual systems. Further, experimental work is carried out to determine how much cognitive load is experienced by both the spectator and the performer during the performance of the trick, which also informs the developed algorithm. After evaluation and optimisation, the final trick is developed into a physical product that is sold in a reputable magic shop in London, UK.

7.1 The Twelve Magicians of Osiris jigsaw; a geometrical illusion

7.1.1 Background

As we have seen, essentially, a magical effect is an event that the observer perceives as being something outside of the normal physical rules of the world. In the previous chapter, tricks were developed that produced the illusion that the performer was able to read the mind of a spectator in some way, by either predicting a choice they would make, or divining a secretly held piece of information. These effects were based on optimising the strength of associations between words, concepts, and images that occurred during a trick. Further, there was a combinatorial issue that a computational system was able to take on. The human trick designer, after initially imagining the overall trick, was still left with work to do, though the computational assistance provided was shown to be valuable to the creation process.

A key goal of systems that are built to be computationally creative is that they take on as much responsibility for the resulting artefact as possible. At this stage in the development of AI systems it is not feasible for a computer to bring forth a completely novel idea, with no human involvement, and realise it in some medium (art, music, magic, etc.). In fact, as we saw in section 3.1.4 on page 51, the current state of the art is some way short of this. However, the situation is incrementally improving.

While computers have been shown, in the previous chapter, to be useful assistants in the domain of natural language, as applied to magic tricks, they may be used to model other categories of tricks more directly. Specifically, tricks that rely on the geometrical arrangement of physical objects. The mathematical model underlying such tricks is directly implementable by a computer, rather than an approximation of natural language systems in the brain that are not perfectly understood, and somewhat nebulous in operation. The psychological factors involved in the tricks are, of course, still vital. We shall see how this direct modelling of a trick allows a computer to take greater responsibility for its creation.

One of the most commonly performed magical effects is that of the vanish - most people will have seen someone make a coin vanish from their hand. Often, these types of effects will be achieved by sleight of hand, or some device utilised by the magician. There is, as noted, a set of tricks that relies directly on both physical (specifically geometrical) properties of the world, see Gardner [34], and properties of the human visual perception system, to engineer these magical vanishes.

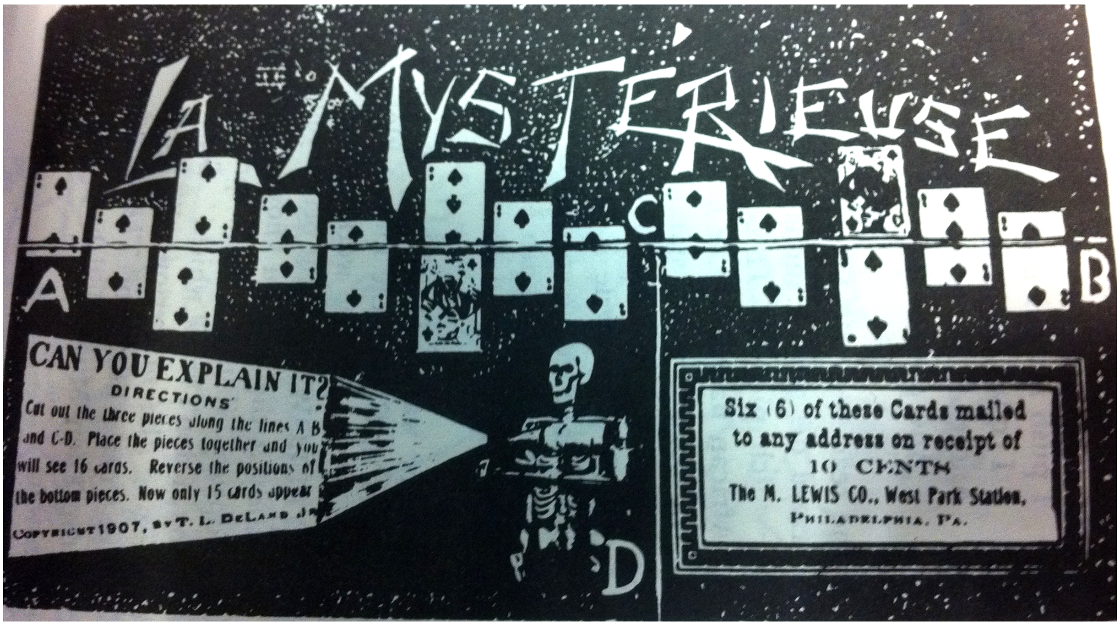
7.1.2 The trick [MAGIC]

The framework is applied to the problem of making an optimally magical jigsaw puzzle, where printed graphics elements appear and disappear depending on how the same jigsaw is constructed. This jigsaw is based on The Principle of Concealed Distribution, an old technique, first developed seriously by Gardner [34]: the geometrical redistribution of segments of one shape among a number of other shapes such that the magnitude of increase in the area of the remaining shapes is imperceptibly small.

The DeLand paradox is an early example of this type of concealed distribution effect, documented by Gardner [34] - see figure 7.1 on page 160. An image showing objects is rearranged such that one of the objects appears to vanish, but in fact has been incorporated into an increase in length of the remaining objects. These types of effect were very popular in the late 1800's and early 1900's; Sam Loyd's Get Off The Earth from 1896 followed The Magic Egg by Wemple & Company, from 1880. DeLand's version appeared in 1907. Fundamentally, each of these tricks rearranges a number of rectangular shapes; the graphic designs laid over the top are often ingenious and allow a narrative to be constructed during the performance of the trick.

A simple, schematic, example of the DeLand paradox is shown in figure 7.2 on page 161. Here, 11 rectangles in the first image become, after suitable rearrangement, only

Figure 7.1 The DeLand paradox original. There are 16 rectangular objects on display: playing cards. After swapping pieces A and B, there are 15.

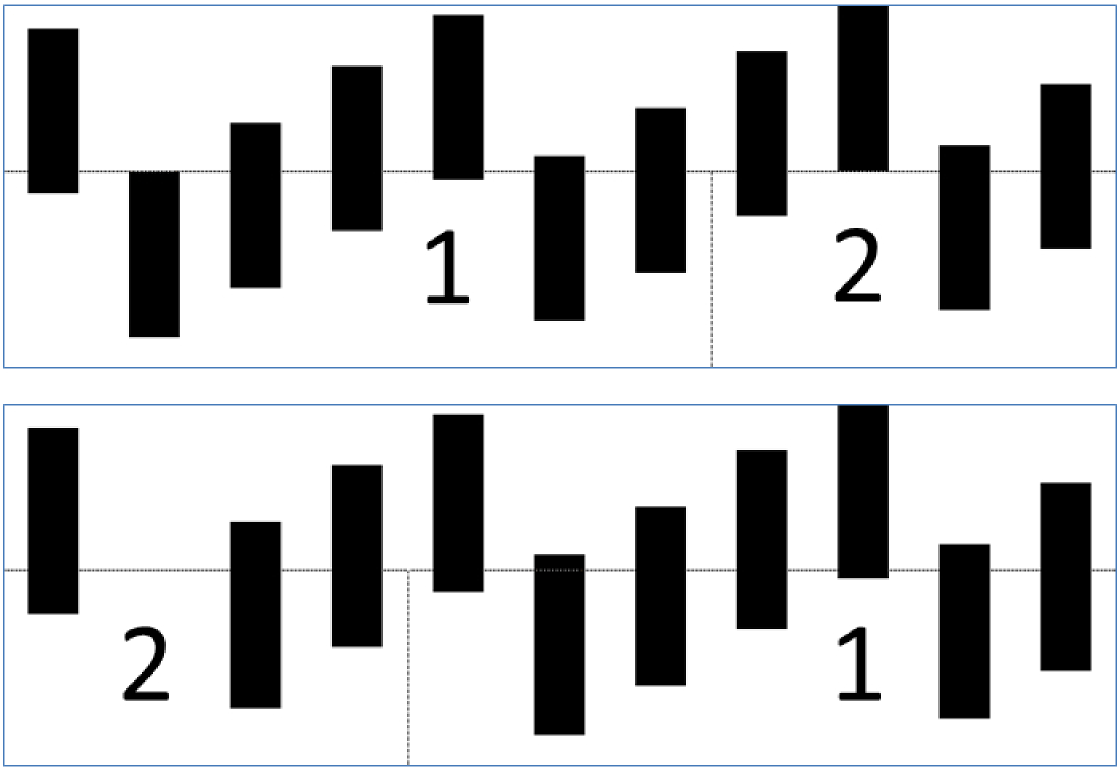


10 in the second. The rearrangement of the pieces is a simple translation in only one dimension (essentially, the x-axis); no rotation of the pieces occurs.

7.1.2.1 Why a jigsaw?

Converting the one dimensional DeLand paradox to a two dimensional multi-piece jigsaw allows for greater flexibility in how the shapes on the surface can be positioned and redistributed, while simultaneously increasing the sense that something physically impossible has happened. A jigsaw puzzle involves a number of interlocking pieces, connected by lugs on one piece that fit into gaps on an adjacent piece. For a jigsaw of the kind described here, the pieces must fit together seamlessly in two different configurations. This way, the first configuration can be presented during performance, taken apart, and reconstructed in the second configuration to show the new image, with fewer rectangles than previously. It is typical for a spectator to assume a jigsaw puzzle can be put together in only one way.

Figure 7.2 The DeLand paradox schema. There are 11 rectangles in the top image. After cutting and swapping the pieces labelled 1 and 2, the resulting image shows only 10 rectangles. The effect relies on the rectangles growing imperceptibly in length.



Thus, the novel trick developed is a jigsaw version of the DeLand paradox, operating in two dimensions. In the DeLand based tricks discussed, generally only one object vanishes. As the effect relies on the spectator not noticing that all of the rectangles have increased slightly in length in the second configuration, it is better for a trick designer to construct the trick using as many starting objects as can be viewed and counted comfortably. The more starting objects there are, the smaller the increase in length in the second configuration, and therefore the less likely the method is to be detected. Here, a version is created on which two objects vanish.

7.1.3 Psychological factors [PSYCH])

The basic psychological factor involved in the jigsaw trick has already been noted: that the spectator must not be able to detect that all the rectangles on the second configuration have all increased in length.

Previous versions of this type of effect have the rectangles displayed vertically in both configurations. This is not necessarily the optimal arrangement; the vertical-horizontal illusion, reported in Robinson [231], dictates that a line displayed vertically will appear longer than an identically sized line displayed horizontally. A jigsaw puzzle operating in two dimensions, and allowing rotations as well as translations of pieces, gives the opportunity to usefully exploit this perceptual illusion.

There are further, conflicting, factors for both the perception, and performance, of the trick.

The jigsaws relevant to this work may be made up of different numbers of pieces, of different basic shapes (rectangles and squares). As mentioned, these must all fit together seamlessly with connecting lugs and gaps for each piece, in both configurations. Crucially, a performer needs to be able to construct, and then reconstruct, the puzzle efficiently, without mistakes. However, more pieces make the method behind the effect harder to resolve in a spectator's mind.

The effect of using increasing numbers of rectangles is also relevant. If too many rectangles are shown they become difficult to count accurately in a reasonable time; the impact of the effect would therefore be diminished as the spectator would be too engaged in counting. Conversely, more rectangles on display can improve the effect, as it is harder for a spectator to determine the method by mentally recombining rectangles. The trick relies on the subject knowing there are different numbers of rectangles in the two different jigsaw configurations.

For the observer, the greater confusion, but stronger effect, occurs when the jigsaw

Psychological factor	**Relevance**	**Parameters**
Threshold of length increase detection for rectangles.	Spectator.	1. The number of rectangular objects on the surface of the jigsaw. 2. The number of objects that vanish.
More jigsaw pieces make the effect more magical, but more difficult to perform.	Spectator and performer.	1. Number of jigsaw pieces that can be practically assembled.
More objects on the surface of the jigsaw make the method harder to determine, but also make the pieces harder to count quickly and easily.	Spectator.	1. Number of objects that can be quickly counted.

Table 7-A: Psychological factors in the jigsaw trick.

is comprised of many pieces, but there are only a few objects on its surface to count. Conversely, for the performer, error free construction and undetectable length increase of the rectangles is enabled with fewer pieces, but more rectangles.

The described psychological factors determine what makes a good jigsaw trick for both the performer and the spectator. Table 7-A on page 163 summarises the various factors, and relevant parameters.

7.1.3.1 Psychophysical experiments

In order to determine a psychological measure of the effect of differing numbers of pieces and rectangles in each jigsaw configuration, that could be used in an optimisation procedure, psychophysical experiments were conducted.

7.1.3.2 Length change

Using the method of constant stimuli, described by Laming [232], the absolute threshold of the amount of change in the length of rectangles able to be perceived was determined. This threshold is defined as the amount of change in length that participants are able to accurately report for more than 50% of stimuli.

Participants were shown pairs of sequentially presented images, separated by a blank screen. Each pair consisted of an image of six rectangles of either all vertical, all horizontal, or mixed orientations, shown for one and a half seconds, followed by a blank screen for one second, followed by a second image of six rectangles also of either all vertical, all horizontal, or mixed orientations. For each image, all rectangles were randomly positioned on screen with none overlapping. The group of rectangles in the second image would either all be the same length as all those in the first image, or would all increase by a certain percentage. The increase ranged from 0% to 30%, in 5% increments. A pair depicting a certain percentage length increase was shown to the participant ten times; the pairings were displayed with a random order of presentation. The participants were asked only to determine if the lengths of the second set of rectangles had increased in comparison with the rectangles in the first image; a yes or no. The absolute threshold of size increase above which participants are able to reliably detect a change is derived from regression fitting a line to the detection of increase data, allowing the accurate derivation of the amount of size increase that can reliably be detected (i.e. greater than 50% of the time).

As anticipated, the vertical-horizontal illusion is evident in the data; the largest absolute threshold value of 21.1% size increase was in effect when subjects were shown an image containing all vertical rectangles, followed by an image containing all horizontal rectangles (denoted VH). The complete set of combinations of orientation resulted in the following absolute thresholds (H=Horizontal, V=Vertical, M=Mixed): VH (21.1%), VM (17.0%), MH (16.3%), VV (15.8%), HV (15.3%), HM (14.0%), HH (13.0%), MV (10.1%), MM (9.5%).

These results on length increase echo recent findings from Harrison et al [233] on perceptible size increase in the links in an animated articulated figure when attention is not fully focussed on the relevant links; in this scenario they also report that size increases of over 20% can go unnoticed. This may point to a general psychological effect:

that higher thresholds of size change perception may be present where attention is not fully focussed.

7.1.3.3 Counting rectangles

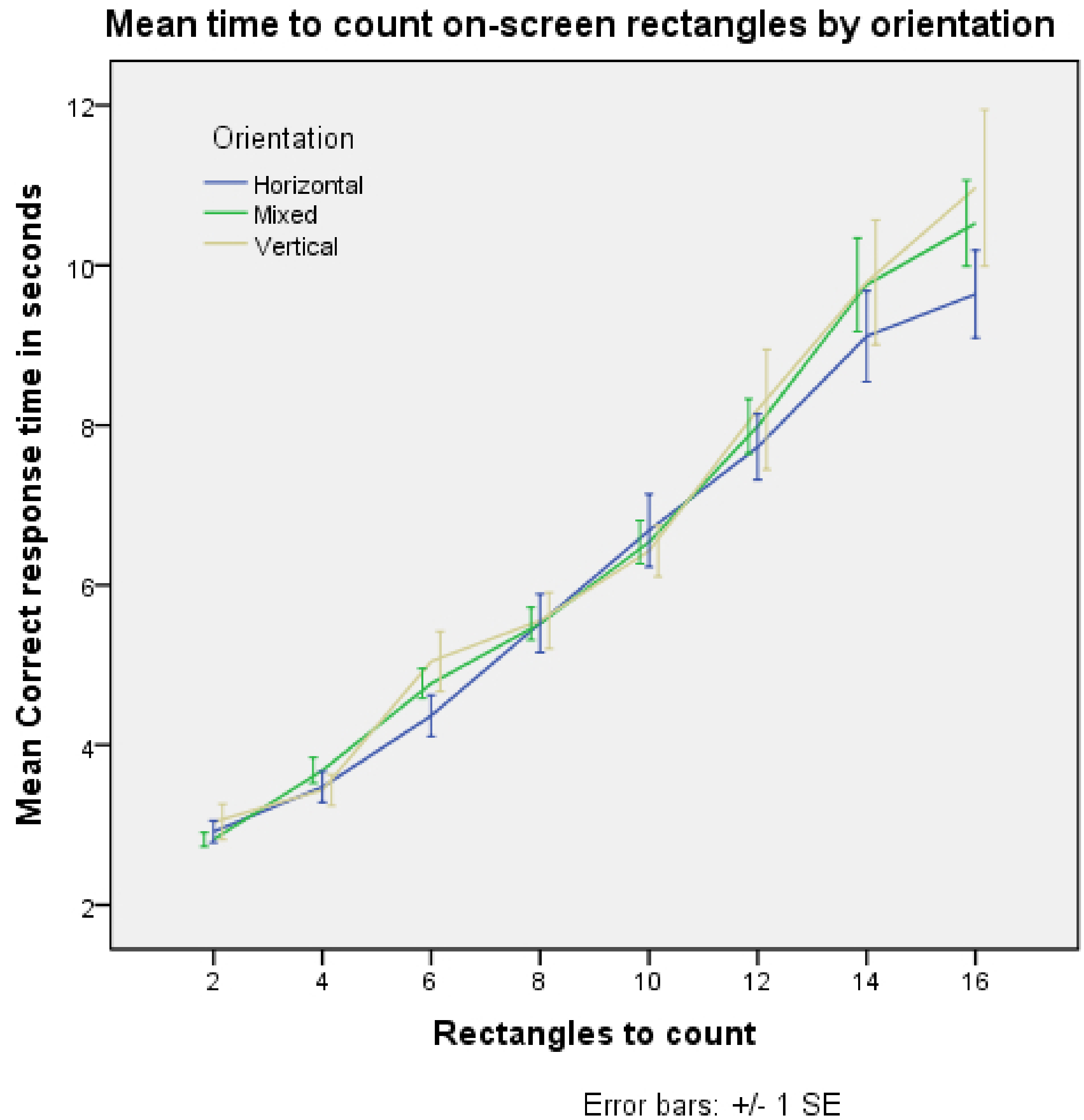
The observer of the trick is required to count the number of rectangles on the jigsaw; the amount of cognitive load this produced was investigated. Previous studies, see Mandler [234], suggest a response time of 250-350 milliseconds per item counted above the subitizing range (the number of items that are able to be counted in a negligible amount of time without much cognitive effort; generally thought to be up to 4 items). An online experiment was performed to determine the rate at which subjects (N=49) were able to count rectangles on a screen, see figure 7.3 on page 166.

During the counting experiment, it was necessary for the participants to find and press an on-screen button, indicating the numbers of rectangles they had counted, and another button to submit their count. From the data, it is estimated that this process takes approximately 2800 milliseconds. Adjusting the data for this, and calculating a per item response time, it appears that as the number of rectangles increase, the underlying time increase per rectangle also increases; this may be explained by participants being more likely to lose count while viewing more rectangles, and therefore having to restart. Further, for larger numbers, any time taken by a participant to check the count is likely higher. Times were recorded only for correct counts. From the gathered data, counting the rectangles takes between approximately 160 milliseconds per rectangle (for 4 rectangles) to approximately 470 milliseconds per rectangle (for 16 rectangles).

7.1.3.4 Cognitive load

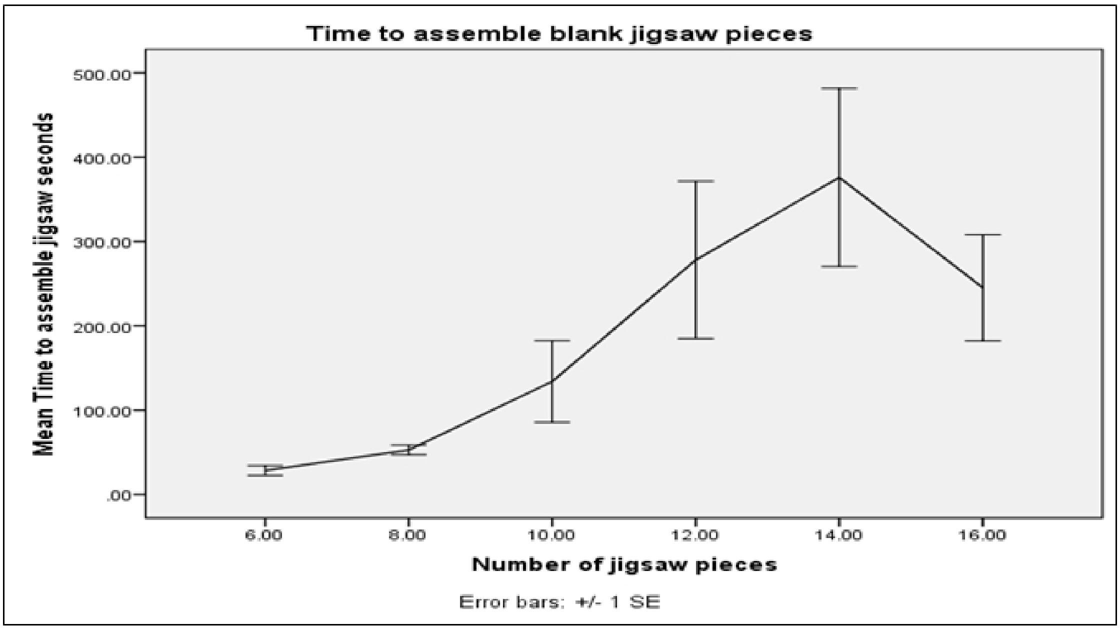
Although a trick with many pieces can overwhelm a spectator attempting to mentally combine and recombine the pieces to determine the method, it may take the performer too long to assemble, and be prone to error, particularly when in a pressurised perfor-

Figure 7.3 Increasing the number of rectangles on screen for a participant to count linearly increases the time taken to accurately count them.



mance situation. After a trial study (N=5), it appears that the time taken for subjects to assemble blank jigsaw pieces into a square shape becomes highly variable beyond eight pieces. See figure 7.4 on page 167.

Figure 7.4 Increasing the number of pieces of a blank jigsaw to assemble as a task seems to become non-trivial for the participants for jigsaws with greater than 8 pieces. As the number of participants in this trial study is low, the high variability of time taken on the non-trivial assembly tasks can lead to lower mean times for higher numbers of pieces.



7.1.4 Controlled problem domain [DOMAIN]

As discussed, the type of trick under analysis, based on DeLand paradoxes, expanded to be formed as a jigsaw, are able to be modelled directly and precisely by a computer. In terms of the physical properties of the jigsaw, there are no ambiguities. Therefore, the problem can be formalised, and an algorithm developed to search for optimal solutions to the problem, that represent magically optimal effects. The psychological factors discussed in the previous section can be applied as constraints on the search process.

There are basic geometrical issues for a jigsaw designer to contend with, such as what shapes of pieces to use, where to place them, and where to position the lugs and gaps on each piece to make viable puzzles. Further, where each rectangle must be positioned so that after rearrangement the desired decrease in the number of rectangles is achieved. The jigsaw trick may be modelled as:

1. Basic overall shape and size of jigsaw (e.g. NxN square).
2. Number of jigsaw pieces.
3. Shape and size of each piece.
4. Configuration of lugs and gaps on each edge of each piece.
5. Number of whole rectangles on the first jigsaw configuration.
6. Size of rectangles.
7. Co-ordinate positions and orientations of pieces in each of the two jigsaw configurations.
8. Co-ordinate positions and orientations of rectangles on the initial jigsaw.

A discretized co-ordinate system is used for all sizes, positions, and orientations. This aids with the search process; a continuous search space, in which, for example, pieces may be placed at any real number co-ordinate position, is more difficult for a computer to contend with due to the essentially infinite number of possibilities, and is unnecessary here.

7.1.4.1 Jigsaw complexity

The general difficulty in programming machines to solve real world jigsaw puzzles lies not only in the arrangement of the tiles in a way that completes the required shape of the board without any gaps, but in the visual identification and matching of the various pictorial elements that make up the whole. Significant efforts have been made by Cho [235] to this end. The jigsaw discussed here does not suffer from this additional complexity, as the properties of each tile is already described within the confines of the computer system. No attempt is made to move from the real world to a digital representation and back again.

Nonetheless, there is significant complexity. The problem of arranging rectangles within a larger bounding rectangle, without any spaces, as is needed for a jigsaw of the type discussed here, is known as rectangle packing. Rectangle packing has been shown, by Korf [236], to be a NP-Complete problem: a problem that is both NP, and NP-hard. NP refers to 'nondeterministic polynomial time' and describes the computational complexity class of a particular set of problems. Problems determined to be in the complexity class P, polynomial time, are those thought to be computable quickly and efficiently [237]; this is known as the Cobham-Edmonds thesis. Solutions to NP-complete problems can be verified (checked for correctness) in P, but there is no known way to compute the solution in P. NP-complete problems generally require heuristic search methods to compute.

In addition to constructing a seamless surface made up of variable sized rectangular pieces, that can be put together, also seamlessly, a second way, the lugs and gaps must also line up in each configuration; this adds additional complexity.

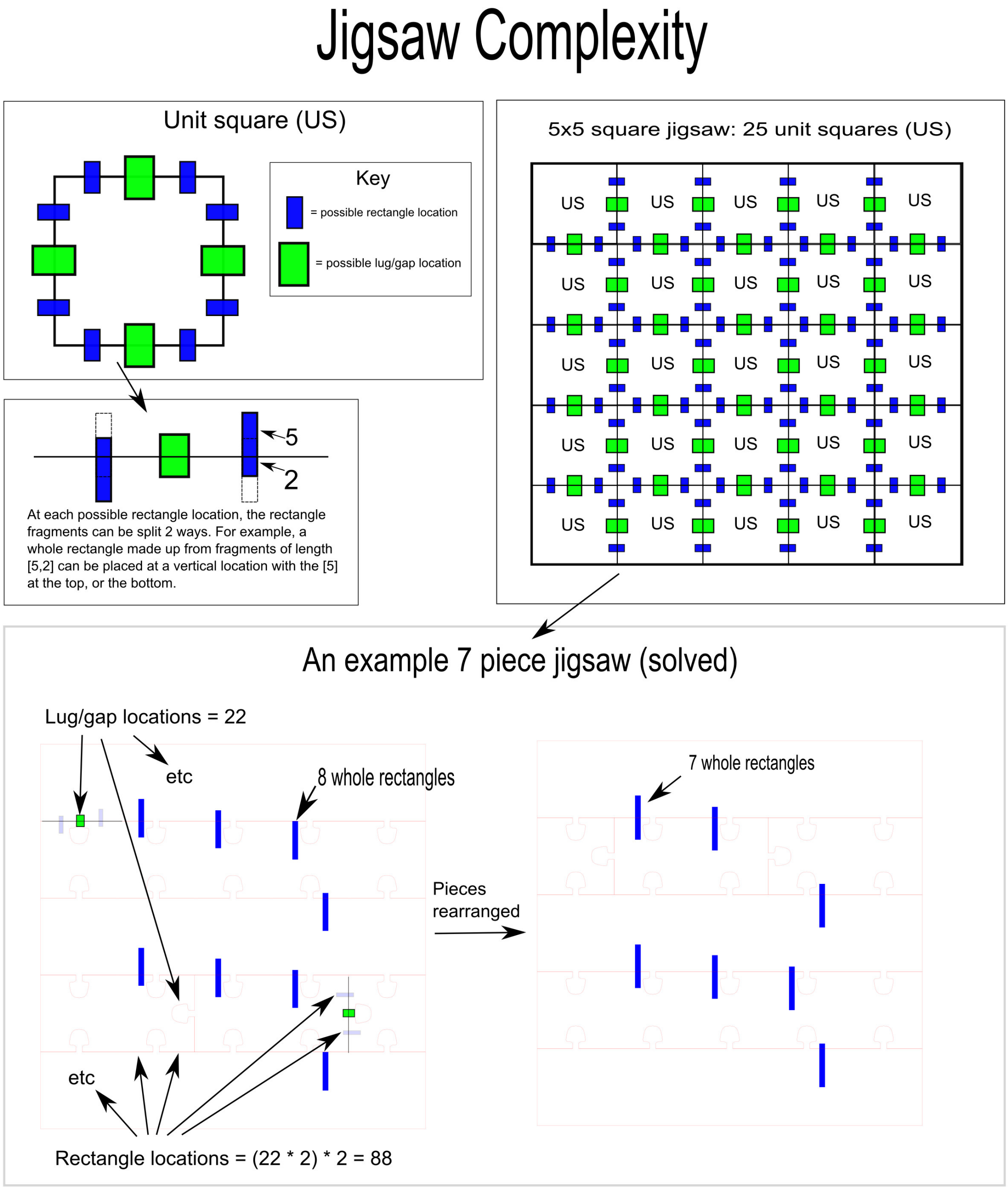
Further, the objects that are displayed on the surface of the jigsaw can also be placed in many different locations in the first configuration; their initial positioning determines their position in the second configuration.

Quantifying the exact number of possible combinations of pieces and object placements depends on the number and size of each used, for each potential solution. A particular square jigsaw with a width and height of 5 units is assumed for an illustrative example: a 7 piece jigsaw, showing 8 rectangular objects in the first configuration, and only 7 in the second.

See figure 7.5 on page 170.

Assuming that each piece can be placed at one of 25 different locations on the $5x5$ square, the potential number of ways to arrange, or tile, 7 pieces (of whatever size and orientation, and ignoring lug and gap positioning) is:

Figure 7.5 An example jigsaw illustrating the complexity of the geometric design problem.



$$Tilings = \frac{25!}{(25-7)!(7!)} = 480700 \tag{7.1}$$

This represents all possible arrangements of pieces, both those that seamlessly cover the surface, and those that do not, including overlapping pieces.

For a viable jigsaw, each piece must fit with its surrounding pieces, leaving no lugs without a corresponding gap to slot into. Dividing the overall square shape of the jigsaw into a grid of unit sizes (i.e. 25 squares making up a $5x5$ grid), provides some insight into the possible combinations of pieces, lugs, gaps, and object placements.

Each unit square may have either a lug or gap in the centre of each of its four sides. Squares at the edge of the jigsaw do not require lugs or gaps. Each side of the square may have any number of potential placement positions for the rectangular objects (one of which will vanish), though to reduce complexity only two sites are defined, at either side of the lug/gap location. See figure 7.5 on 170.

For a square jigsaw of dimensions $5x5$, there are 40 potential locations (20 horizontal, and 20 vertical) that require a lug or a gap. Whether each location on each piece is defined as having a lug or a gap depends on the size and placement of the pieces. For example, a piece with width 5, height 1, has 5 locations on its top, and 5 on its bottom that can feature either a lug or a gap. Therefore, each side has 32 (2^5) possible distinct configurations of lugs/gaps. The left and right sides meet the edge of the jigsaw, and therefore require none.

The $5x5$ square seamlessly tiled by 7 pieces in figure 7.5 on page 170 has 22 locations that require lugs or gaps. Therefore, this particular set of 7 jigsaw pieces has:

$$LugGapCombinations = 2^{22} = 4194304 \tag{7.2}$$

This represents all the possible distinct combinations of lug and gap placements, including those that are not viable (e.g. a lug from one piece meets a lug from another piece).

Starting from a fully formed jigsaw displaying 8 rectangular objects, the pieces must be rearranged into a second solution featuring only 7 rectangles; further to this, each rectangle must be of the same length. A rectangular object displayed on the surface of the jigsaw can be split into two sections, or fragments, if it crosses a boundary between two pieces.

Analytically, in order for there to be 8 whole rectangles displayed on the first configuration, and only 7 on the second configuration, and for each to be of equal length, there are required to be 4 distinct pairs of rectangle fragments of certain unit lengths. This relationship can be seen clearly in the following description. The 4 required pairs of rectangle fragments (making up 8 whole rectangles) are:

1. A pair of fragments that make up two whole rectangles of 7 unit lengths, each fragment pair represented as [7, 0], to indicate a rectangle 7 units of length in one jigsaw piece, and 0 (zero) units of length in another. The 0 (zero) length fragment is described in the interests of clarity of explanation.

2. Similarly, two rectangle fragments of [6,1] - i.e a whole rectangle of length 7 units, with 6 units of length in one jigsaw piece, and 1 unit of length in another piece.

3. Two rectangle fragments of [5,2]

4. Two rectangle fragments of [4,3]

Removing from consideration the two rectangle fragments of unit length 0 (zero) (from the two [7,0] pairs), there are fourteen individuated rectangle fragments of lengths:

[7], [7], [6], [6], [5], [5], [4], [4], [3], [3], [2], [2], [1], [1]

This allows, in the second configuration of the jigsaw, pieces to be recombined into only 7 whole rectangles of length 8:

[7,1], [7,1], [6,2], [6,2], [5,3], [5,3], [4,4]

On a $5x5$ jigsaw there are 4 available rows, and 4 available columns, for object placement (the borders of the jigsaw are excluded). On each row and column, there are 10 distinct x or y co-ordinates (accordingly) at which objects can be placed (2 locations per lug/gap). At each x or y position, an object can placed in one of two exact locations. For the illustrated example, that has 22 lug/gap locations, the total number of available placement positions is:

$$PlacementPositions = (LugGapLocations \times 2) \times 2 = (22 \times 2) \times 2 = 88 \tag{7.3}$$

Each whole rectangle placed reduces the number of $PlacementPositions$ by 1. There are many different ways to place 8 whole rectangles onto 88 different locations:

$$Placements = \frac{88!}{(88-8)!(8!)} = 2.59 \times 10^{15} \tag{7.4}$$

Taking into account the jigsaw pieces, the lugs and gaps, and the rectangle fragments, we arrive at the following number of jigsaw combinations to search:

$$JigsawCombinations = Tilings \times LugGapCombinations \times Placements = 5.23 \times 10^{27} \tag{7.5}$$

Although this is a naive total that simply states all the possible ways to configure the various elements for a particular number of pieces arranged a certain way, using a specific number of rectangular objects, inclusive of non-viable configurations, it illustrates the enormous search space that must be traversed. There is, for a human designer, an intractable combinatorial explosion of possibilities for jigsaw designs (even when fixing the number of pieces and objects, as shown). Indeed, even for a computer, there are simply too many ways to put the jigsaw together to search through them all in a reasonable time.

Table 7-B on page 175 outlines the various parameters identified in the analysis process of the jigsaw trick; the complexity of the design problem, as defined, points

toward a computer being the most viable optimisation method.

7.1.5 Computational technique [AI]

An automated system that is capable of synthesising the various geometric and perceptual elements discussed, to design novel jigsaw tricks to flexible specifications, is something approaching the computationally creative entity previously mentioned; the computer takes on most of the responsibility for the design of the resulting artefact. Such a system can be configured with the appropriate psychological constraints that have been outlined, to guide its design process: maximising the ease of performance and concealment of underlying mechanics, while minimising the cognitive effort required by the observer to experience the magical effect.

Optimal solutions that maximise the magical effect defined by the psychological constraints are desirable. Optimisation algorithms can find multiple potential solutions, which are referred to as local solutions, as there may exist one overall best global solution the technique does not identify. This issue around recovering a local or global solution is well known, and is dependent on initial conditions used, length of time the algorithm is run, and the algorithm tuning parameters used (Russell [110] provides detailed discussions).

7.1.5.1 Genetic Algorithms

Genetic Algorithms (GAs) are excellent optimisers for combinatorial problems, as shown by Goldberg [121]. GAs are able to perform searches through large, complex problem spaces that contain (undesirable) local optima. The jigsaw is in fact a multi-objective optimisation problem; conflicting constraints mean there is not necessarily a single solution where each objective is optimal; a balance may need to be struck.

A GA is an evolutionary approach to solving difficult search problems, modelled on

Element	**Function**	**Parameter**	**Relevance**	**Design**
Basic overall shape and size of jigsaw.	The dimensions of the jigsaw.	1. Unit *width* and *height*.	Spectator and performer.	Computer.
Number of jigsaw pieces.	Determines the ease of assembly for the performer, and the level of geometric confusion for the spectator.	1. The number of pieces used.	Spectator and performer.	Computer.
Shape and size of each piece.	Determines the tiling of the jigsaw surface.	1. Different sets of pieces with different shapes.	Spectator and performer.	Computer.
Configuration of lugs and gaps on each edge of each piece.	Determines whether the pieces fit together seamlessly in both configurations.	1. Lug/gap configuration on each piece.	Spectator and performer.	Computer.
Whole rectangles on the first jigsaw configuration.	Determines how easy the rectangles are to count for the spectator, and how many can be vanished (geometrically).	1. Number of rectangles used.	Spectator.	Computer.
Length of whole rectangles.	Determines how many can be vanished (geometrically), and whether the subsequent length increase will be detectable.	1. Unit length of rectangles.	Spectator.	Computer.
Co-ordinate positions and orientations of pieces in each of the two jigsaw configurations.	Partially determines how the rectangular objects are redistributed on the second configuration of the jigsaw (i.e. whether they are recombined in a way that vanishes one or more rectangles).	1. The co-ordinates used.	Spectator.	Computer.
Co-ordinate positions and orientations of rectangles on the initial jigsaw.	Partially determines how the rectangular objects are redistributed on the second configuration of the jigsaw (i.e. whether they are recombined in a way that vanishes one or more rectangles).	1. The co-ordinates used.	Spectator.	Computer.

Table 7-B: Problem domain parameters for the jigsaw trick.

the process of natural selection. During the operation of a GA, populations of candidate solutions are evolved towards increasingly optimal solutions. A candidate solution (or, phenotype) can be scored according to its fitness to survive in its environment (the search space); a fitness function will typically be defined that builds in the objectives that the algorithm designer would like an optimal solution to meet. A candidate solution is often defined as a string of 1s and 0s, that represents its various properties - a binary string. These strings can be mutated and mated with each other to form new candidate solutions.

Starting from an initial population of candidate solutions, an iterative process is followed. Each population in each iteration is known as a generation. During each iteration, the fitness of all individuals in a population is evaluated according to the defined fitness function. Typically, the fittest individuals are selected from the current generation to form a seed group for the next generation. These individuals are then randomly mutated (changing a 1 to a 0, or vice versa), with a certain probability (the mutation rate). They are also randomly selected to breed with each other, in a process known as crossover (with an associated crossover rate): sections of each binary string from two individuals are joined to form a new individual. These newly created and mutated individuals form the next generation's population, and the next iteration is computed. The process halts either after a certain number of generations, or if the search objectives have been met.

7.1.5.2 The Jigsaw GA

The geometric problem inherent in jigsaw design has similarities with combinational electronic circuit design. GA systems to generate solutions in this problem domain were first developed by Louis with his work on structure design [124], and followed by others, including: Arslan's efforts on the structural synthesis of VLSI circuits [126], and Coello's GA automated process to minimise the number of gates used by a circuit [238].

A GA based system was developed to design jigsaws. Data from the psychophysical experiments were used as objectives in the GA's fitness function. A range of values for each of the model parameters can result in workable, though not optimal, solutions. Some parameters affect the viability of each candidate solution during the design process; for example, a basic requirement is that the pieces of the jigsaw must fit together to form the same basic overall shape, covering the same surface area (i.e. no gaps).

The specific constraints, used in fitness evaluation, as applied to the model, are detailed below. Hard constraints (denoted [HARD]) are those that define a viable jigsaw (i.e. a candidate solution that does not meet the hard constraints is not a valid solution; e.g. there may be lugs that do not have a gap to slot into). Optimisation constraints (denoted [OPTI]) are those to be minimised or maximised to search for the best, as defined, magic jigsaw:

1. [HARD] Area of first and second jigsaw solution covered by generated pieces. This should cover the same area as the defined shape of the desired solutions, with no gaps.

2. [HARD] Number of pieces that are fully connected by jigsaw lugs in the first and second jigsaw solution. All lugs must connect to a gap. No spare gaps.

3. [OPTI] Number of whole rectangles of the required size on the second jigsaw. Minimise this number (this defines how many rectangles have 'vanished').

4. [OPTI] Number of rectangle fragments on the second jigsaw. Minimise this (zero is optimal).

5. [OPTI] Spatial distance of rectangles from configurable points on the jigsaws. Pleasing designs cover the surface of the puzzle more evenly (relevant to the spectator).

6. [OPTI] Total number of jigsaw pieces, scored from a scale mapped from experimental data (relevant to the performer and the spectator). Eight pieces is defined

as optimal. Minimise the deviation from this.

7. [OPTI] Total number of rectangles, scored from a scale mapped from experimental data (relevant to the spectator). Minimise this.

8. [OPTI] Rectangle orientation score for each jigsaw, scored from a scale mapped from experimental data (relevant to the spectator). Optimally all rectangles on the first solution are vertical, while all on the second are horizontal.

Multi-objective optimisation techniques are available that can be applied to problems such as the jigsaw produced here, where conflicting constraints mean there is not necessarily a single solution where each objective is optimal; a balance must be struck. Where fitness functions contain conflicting constraints there can be any number of groups of optimal (non-dominated) candidate solutions, termed Pareto fronts, at any point in the optimisation process - a non-dominated solution is a solution where none of the component fitness values can be improved without diminishing some of the other values.

This type of multi-objective problem needs a specialist GA algorithm; a NSGA-II (from Deb [123]) derived GA coupled with a rectangle packing algorithm (from Lodi [106]) was selected for use. Rectangle packers are used to efficiently pack shapes into containers. The standard NSGA-II algorithm was applied, with the constraints outlined above built into its fitness function, using the rectangle packer to generate valid candidate jigsaws from a given set of basic shapes. The NSGA-II algorithm introduces the crowded-comparison operator to the GA algorithm, used as a metric to compare candidate solutions to each other based on the rank of each solution and the density of other nearby solutions. The crowded comparison operator is used as part of the selection mechanism to ensure diversity in the population, allowing the algorithm to more evenly explore the search space.

During this selection phase of the process, in which the next generation of candidate solutions is created, a tournament selection method is used. A number of randomly chosen individuals are compared (in a kind of tournament); the winner is the one with the highest fitness score. This individual is then put forward for a crossover operation with another winner of another tournament. The two are combined using two-point crossover to form a new individual. Two-point crossover refers to the process of selecting two points on the parent individual's binary strings, and swapping all digits between, resulting in a new binary string (a new individual). This new individual is entered into the subsequent generation's population.

Candidate jigsaw solutions are typically encoded as approximately 200-bit entities, with differing amounts of bits used for more or less complex jigsaws (more or less pieces, more or less surface objects). A per bit mutation rate of 0.004, and a crossover rate of 0.9, was found to be effective.

See figure 7.6 on page 180 for an overview of how the framework was applied to the jigsaw design problem. This puts the various components in context with each other, of which the AI engine is only a part, albeit a crucial one.

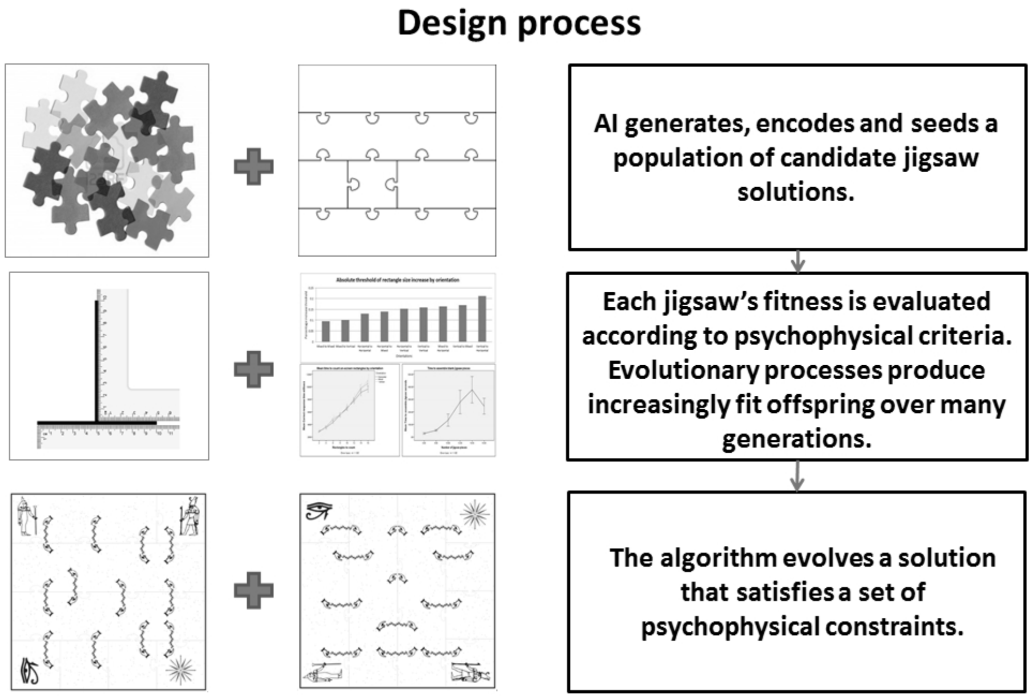
With this optimisation configuration the automated system is capable of synthesising the various geometric and perceptual elements discussed, to design novel jigsaw tricks to flexible specifications.

Configured with the discussed psychological and physical constraints, the system generated an optimal, as defined, jigsaw pictured in figure 7.7 on page 181. This particular jigsaw has been augmented with a graphical design based on Egyptian mythology, where 12 'spells' magically become only 10, after the jigsaw has been rearranged. This became the basis for a productised version of the trick, as we shall see later. This version of the jigsaw trick is named **The Twelve Magicians of Osiris**.

7.1.5.3 Jigsaw trick algorithm computation time

The implemented process, as described by the algorithms in appendix C on page 272, converges to solutions in less than fifty generations, more often in less than fifteen - the

Figure 7.6 The Genetic Algorithm driven jigsaw design process. Geometric and empirically derived psychological constraints are used by a GA to design a perceptually compelling jigsaw magic trick.



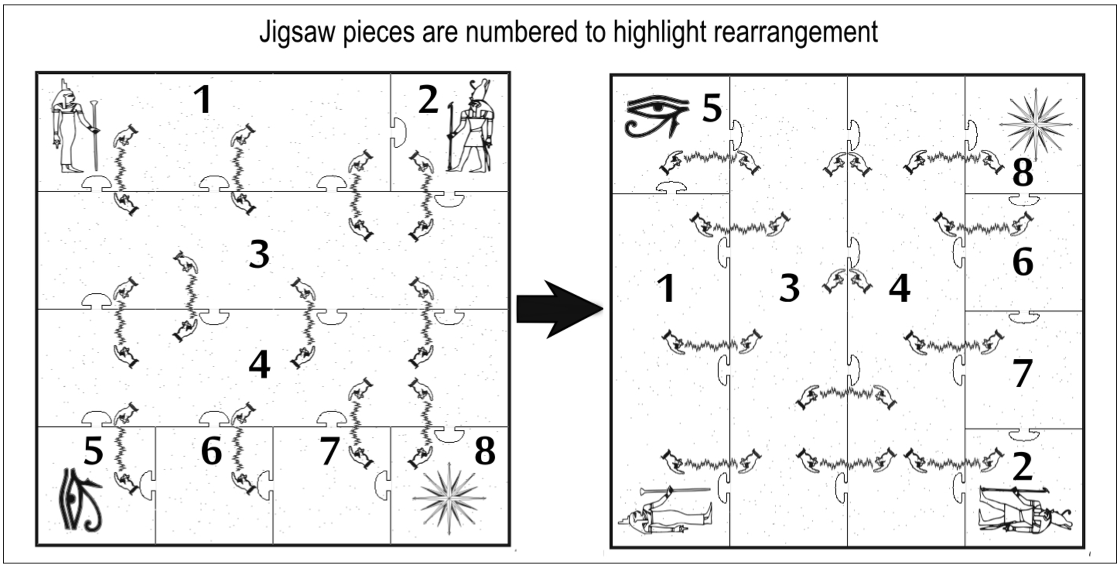
number of pieces and number of rectangles increases the complexity. The computation time to design the example featured was approximately two minutes on a desktop PC with an Intel Core i5 processor.

7.1.6 Technology [TECH]

No special digital technology is needed for the presentation of the jigsaw trick, as it is a physical item. Laser cutting devices were used to manufacture the jigsaws. The surface of each jigsaw was etched by the laser cutter, before being either painted or varnished.

Examples of the laser cut jigsaws can be seen in figure 7.8 on page 182.

Figure 7.7 The magic jigsaw. The first configuration, shown on the left, depicts twelve 'spells', two of which subsequently seem to vanish in the second configuration, shown on the right. Each 'spell' in the second configuration has grown imperceptibly in length. The numbers on the pieces have been added here to help show where each piece starts and ends in each configuration; the real jigsaw as sold is not numbered.



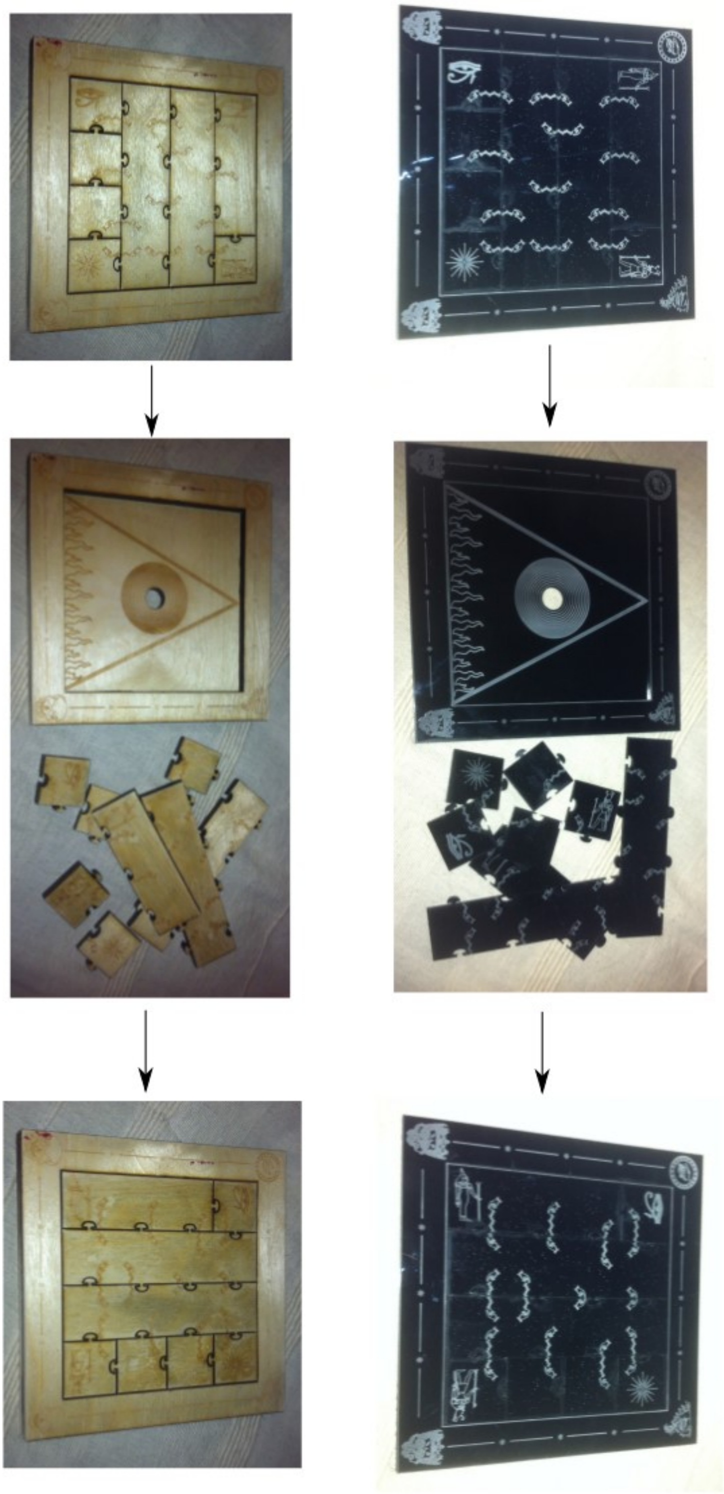
7.1.7 Evaluation [EVAL]

The magical effect of The Twelve Magicians of Osiris was empirically evaluated (N=100), using a plastic version of the laser cut jigsaw, and compared to the ratings from those gathered for the classic magic tricks (N=96), reported in section 4.2.6.1 on page 77.

The participants for the jigsaw trick evaluations were recruited from university mailing lists, and from disseminating details of the experiment on twitter. To simplify the questionnaire, age, gender or country of origin data was not asked for from the participants. Participants were shown a video, and asked to rate their enjoyment of it on the scale (Hated (=0) through Loved (=4)); for the jigsaw trick experiment participants were also asked how much they enjoyed magic generally, using the same scale.

To investigate the effect of narrative, different versions of the jigsaw trick were produced. The jigsaw trick videos shown were:

Figure 7.8 Plastic and wooden versions of The Twelve Magicians of Osiris, as sold.



Plastic and wooden versions of The Twelve Magicians of Osiris

1. The full jigsaw trick, with a narrative describing the events shown, which frames the trick in a mythological story based in ancient Egypt; the vanishing rectangles are 'spells'.

2. The same trick, but with no narrative describing the events shown; the jigsaw is simply rearranged on screen in a mechanical way, with a finger pointing to the 'spells'.

3. The jigsaw is rearranged on screen, but no 'spells' vanish, therefore nothing magical has occurred; a narrative is supplied, very similar to the Egyptian themed mythological story supplied previously, but with a different ending that does not reference anything vanishing.

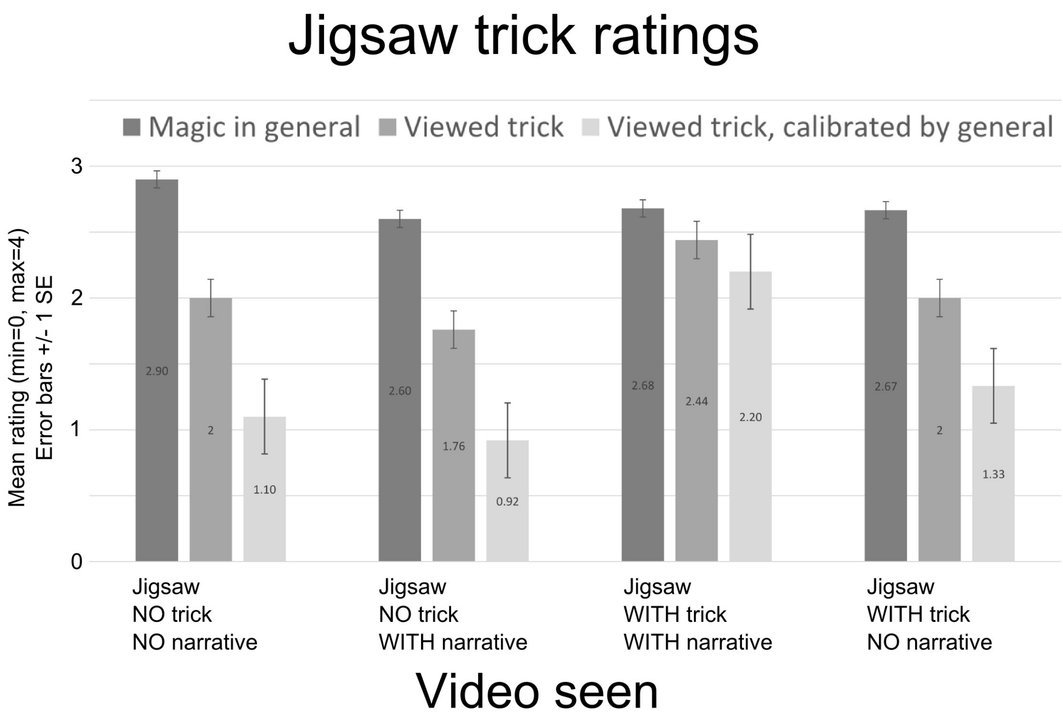
4. The jigsaw is rearranged on screen, but no 'spells' vanish, therefore nothing magical has occurred; no narrative is supplied.

For ratings of each jigsaw trick, see figure 7.9 on page 184. A one-way between subjects ANOVA was conducted to compare the effect of video seen on enjoyment rating for videos seen in Jigsaw NO trick NO narrative, Jigsaw NO trick WITH narrative, Jigsaw WITH trick WITH narrative, and Jigsaw WITH trick NO narrative conditions. There was a non-significant effect of video seen on enjoyment rating at the $p < 0.05$ level for the four conditions [$F(3, 96) = 2.515$, $p = 0.06$]. Initial results suggest using more subjects in the experiments may result in a significant difference between videos seen.

The jigsaw trick with a full narrative scores comparably with classic tricks (though they were presented without a narrative). The calibrated values emphasise weak ratings. The difference between the general rating and the trick rating, for the full jigsaw trick with a narrative, is 0.24. The difference between the other video ratings and their associated general ratings is much higher: jigsaw, no trick, no narrative (0.9); jigsaw, no trick, with narrative (0.84); jigsaw, with trick, no narrative (0.67).

Table 7-C on page 184 summarises the results of the generated tricks.

Figure 7.9 The jigsaw enjoyment ratings are shown, along with the reported enjoyment of magic in general by the viewers of each video. The third rating is a calibrated value, based on the formula $CalibratedRating = TrickRating + (TrickRating - GeneralRating)$. The jigsaw trick with a full narrative scores comparably with classic tricks. The calibrated values emphasise weak ratings. The difference between the general rating and the trick rating, for the full jigsaw trick, is 0.24.



Trick	**Mean enjoyment score reported for the trick**	**Mean enjoyment score reported for magic in general**	**Difference**
Princess card trick	3.58	3.79	0.21
Association trick	3.27	3.50	0.23
Crystal Ball trick	3.50	3.52	0.02
Jigsaw trick	2.44	2.68	0.24

Table 7-C: Summary of enjoyment scores reported by groups viewing each trick. Lower Difference scores are better.

It is interesting to note the role that introducing a narrative to the jigsaw trick has on its enjoyment rating; the worst score comes from the version where nothing magical occurs, and no narrative is supplied (unsurprisingly). Introducing a narrative to this version improves the enjoyment of the experience; however, the version showing a magical effect, but with no attached narrative, scores better (using the difference metric). The implication is that if the viewer is expecting a magic trick and nothing magical happens, this has a detrimental impact on their enjoyment, even if a story is told. Narrative, however, does play a large role: the highest scoring video supplies both a narrative and a magical effect. While it might be expected that the version that shows a magical effect but has no narrative would score similarly to the classic effects (also presented without narrative), it should be noted that the jigsaw trick arguably relies more heavily on the narrative to explain what is occurring than the other tricks - crucially to highlight that something has vanished - the classic effects are all easy to understand without an accompanying narrative.

Participants who viewed the jigsaw tricks were also asked to select a word to describe their reaction to the tricks they had witnessed. This evaluation was performed with a longer list of words than the distilled list used for the standard evaluation; the longer list was, however, also selected from words describing the classic magic tricks. Not all participants (from N=100) chose to select a word to describe their reaction. What follows is a breakdown of the number of times a word was reported by a participant after viewing the full jigsaw trick (with vanishing 'spells' and a narrative). Most responses are positive, or express a sense of something unexplainable having occurred: Bored (1), Clever (5), Clumsy (1), Confused (3), Cool (4), Disappointed (2), Dull (5), Easy (1), How? (6), Interested (5), Predictable (2), Puzzled (5), Rubbish (1), Sceptical (3), Simple (4), Slick (2), Surprised (1), Unexpected (2), Wonder (1).

In a final qualitative study (N=7), when asked to describe how the trick worked, or any suspicious moments arising, four participants reported having no idea, two made accurate guesses but were hesitant, while the remaining participant explained the trick as an optical illusion.

7.1.8 Validation [VALID]

A physical version of the jigsaw was productised as a wooden, and plastic, puzzle, laser cut and printed, and packaged with instructions for sale as The Twelve Magicians of Osiris. See figure 7.8 on page 182, and figure 7.10 on page 189. The jigsaw was included as part of the inventory in a reputable and well established magic shop in London, UK, (Davenports), and the two runs of the product sold out (30 units). The cost for the jigsaw, £20, was set in conjunction with the shop owner, an experienced salesman of magic tricks, who was able to provide what, in his professional opinion, was a competitive price compared to other similar tricks. This is direct evidence of the efficacy of the framework methods to create novel, practical and saleable magic effects. These sales are considered as evaluation metrics in a research project, rather than as evidence of commercial value, but it is worth noting the shop requested further stocks.

A wooden version of The Twelve Magicians of Osiris trick was accepted into the Magic Circle library (London, UK) by Terry Wright (Deputy Executive Librarian) in August 2013.

7.1.9 Conclusions from the Twelve Magicians of Osiris trick

In this chapter, the design and optimisation of the Twelve Magicians of Osiris trick has been described, resulting in a GA system capable of flexibly designing jigsaw tricks to order.

The framework has been applied, integrating for the first time a computational system that autonomously, once configured, designs artefacts that can be directly used as a magic trick without further refinement from a human trick designer. Of course, many of the critical design decisions have already been taken by a human designer during the trick conception and algorithm design phases. However, the psychological factors involved in this type of trick have been empirically evaluated, and subsequently built in to the computational system, that uses them as constraints to guide its search process toward an optimal, or near optimal, artefact. The computer has taken on more responsibility for the design of a trick than we have seen in previous chapters. The inherent complexity of the design problem presented by the jigsaw, both geometrically and psychologically, has been tackled by a GA system configured in a particular way. It is argued that the resulting product derived from the process could not have been designed by a human in a similar amount of time.

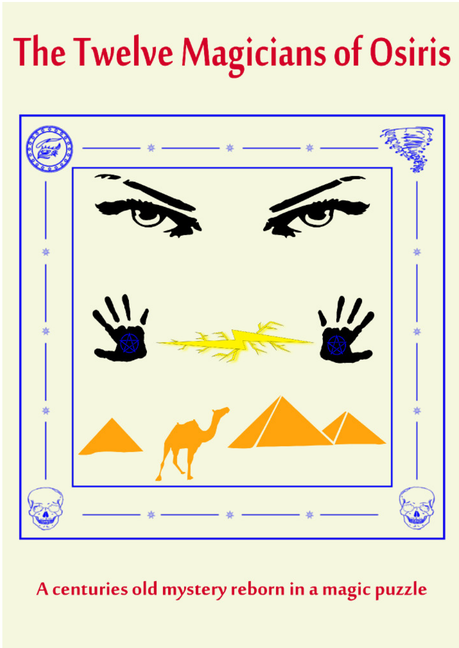
The jigsaw artefact created by the framework was evaluated in a real world setting, receiving high enjoyment scores from spectators who had no prior knowledge as to the nature of its conception; this was purposefully done to avoid the kind of biased thinking Colton has reported [188] in subjects viewing art created by a computer. Although the idea of an AI created magic trick is likely to pique curiosity in an audience, the real test is whether it can compete with other, human created, magic tricks on a level playing field. The evaluation and validation phases conducted suggest that it can.

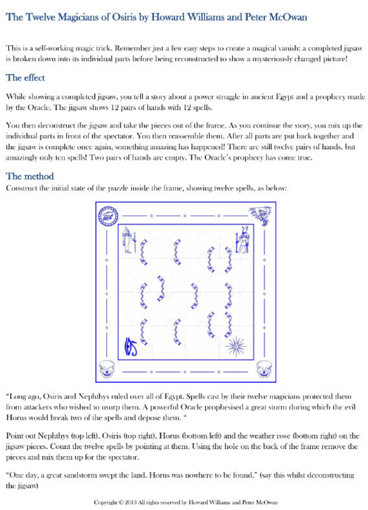
The final iterative step that could be taken with the jigsaw, would be to take the results from the evaluation and validation phases, and feed them back into earlier stages of the framework, to inform further optimisation. This step has not been taken, though the framework as conceived is built to naturally allow this. A potentially beneficial investigation would be to perform an evaluation of different types of graphics (i.e. not just Egyptian themed), and to feed the results back to the AI phase to optimise not just the geometric physical properties, but also the graphical designs, toward an enhanced artefact. Further, it would be interesting to perform evaluations around whether the presence of the hands (or similar 'book-end' objects) on the Osiris trick enhance or detract from the overall effect. Despite the attempt to capture the fundamental elements involved in the trick, the imaginable variations are endless. The presented framework has been designed to allow for the easy integration of new observations and techniques for future iterations of each trick it is applied to.

7.2 Summary

In this chapter a new trick was designed by an AI system configured with constraints derived from experimental data about aspects of human perception and cognition. The output of the system was shown to be a viable magic trick of interest to magicians: a physical product sold at a magic shop in London, UK. In the next chapter, all of the framework elements thus far investigated will be shown working together to automate a flexible magic trick design system based on AI methods that results in a trick that exploits the potential of sophisticated modern technology, a mobile phone, to successfully present a novel effect: a magic trick app that can be sold to magicians and dedicated members of the public alike.

Figure 7.10 The front cover and instructions booklet included in The Twelve Magicians of Osiris jigsaw trick product.





The Twelve Magicians of Osiris by Howard Williams and Peter McOwan

This is a self-working magic trick. Remember just a few easy steps to create a magical vanish: a completed jigsaw is broken down into its individual parts before being reconstructed to show a mysteriously changed picture!

The effect

While showing a completed jigsaw, you tell a story about a power struggle in ancient Egypt and a prophecy made by the Oracle. The jigsaw shows 12 pairs of hands with 12 spells.

You then deconstruct the jigsaw and take the pieces out of the frame. As you continue the story, you mix up the individual parts in front of the spectator. You then reassemble them. After all parts are put back together and the jigsaw is complete once again, something amazing has happened! There are still twelve pairs of hands, but amazingly only ten spells! Two pairs of hands are empty. The Oracle's prophecy has come true.

The method

Construct the initial state of the puzzle inside the frame, showing twelve spells, as below:

"Long ago, Osiris and Nephthys ruled over all of Egypt. Spells cast by their twelve magicians protected them from attackers who wished to usurp them. A powerful Oracle prophesised a great storm during which the evil Horus would break two of the spells and depose them. "

Point out Nephthys (top left), Osiris (top right), Horus (bottom left) and the weather rose (bottom right) on the jigsaw pieces. Count the twelve spells by pointing at them. Using the hole on the back of the frame remove the pieces and mix them up for the spectator.

"One day, a great sandstorm swept the land. Horus was nowhere to be found." (say this whilst deconstructing the jigsaw)

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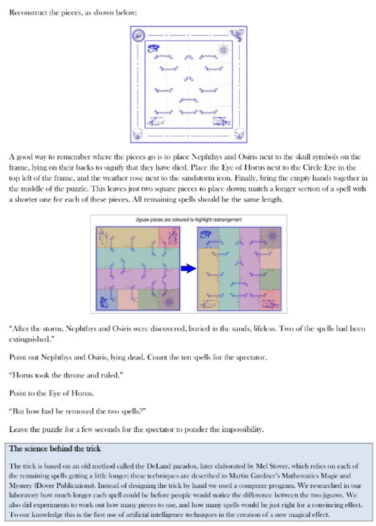


Reconstruct the pieces, as shown below:

A good way to remember where the pieces go is to place Nephthys and Osiris next to the skull symbols on the frame, lying on their backs to signify that they have died. Place the Eye of Horus next to the Circle Eye in the top left of the frame, and the weather rose next to the sandstorm icon. Finally, bring the empty hands together in the middle of the puzzle. This leaves just two square pieces to place down; match a longer section of a spell with a shorter one for each of these pieces. All remaining spells should be the same length.

Jigsaw pieces are coloured to highlight rearrangement

"After the storm, Nephthys and Osiris were discovered, buried in the sands, lifeless. Two of the spells had been extinguished."

Point out Nephthys and Osiris, lying dead. Count the ten spells for the spectator.

"Horus took the throne and ruled."

Point to the Eye of Horus.

"But how had he removed the two spells?"

Leave the puzzle for a few seconds for the spectator to ponder the impossibility.

The science behind the trick

The trick is based on an old method called the DeLand paradox, later elaborated by Mel Stover, which relies on each of the remaining spells getting a little longer; these techniques are described in Martin Gardner's Mathematics Magic and Mystery (Dover Publications). Instead of designing the trick by hand we used a computer program. We researched in our laboratory how much longer each spell could be before people would notice the difference between the two jigsaws. We also did experiments to work out how many pieces to use, and how many spells would be just right for a convincing effect. To our knowledge this is the first use of artificial intelligence techniques in the creation of a new magical effect.

Chapter 8

Exploiting the potential of a computer during magic trick performance

As discussed in Chapter 7, AI techniques can be successfully deployed as computational aids for a magic trick designer. There are many benefits to this approach, including enhanced flexibility of trick design, and reduction in time spent on combinatorial problems. The output of an AI system was shown to be effective: a physical product was manufactured from the design, and subsequently sold to magicians. During this chapter, an AI system is developed that offers similar flexibility and design power. A new type of trick, based on probabilistically predicting spectator selections based on empirical data, is introduced. Further, a method of presentation is developed that relies on mobile phone technology to secretly aid the performance of the trick, in contrast to the apps in chapters 5 and 6, whose role in the process is more readily detectable by an audience. As in chapters 6 and 7, the AI system is configured with constraints derived from observations of psychological phenomena, and the tricks are optimised with both performance and perception of the trick built into the constraints.

8.1 Combinatorial cards; Phoney: a smart trick for smartphones

8.1.1 Background

The framework has been shown to successfully integrate AI techniques into the trick design process; these algorithms can be configured with constraints derived from psychological observations, to search for magically optimal effects. The previous chapter outlined an approach to trick design that allowed a computer to take on a large amount of responsibility for the created artefact. As we have seen, the implications of the use of computers as a vital creative tool in a design process have been discussed in depth elsewhere, notably by Boden [239] and Bentley [125]. For the purposes of the framework under discussion, it has been shown that a trick designer is, when necessary, able to pass on a large amount of responsibility for a trick's design to a computer, leading to previously unavailable artefacts for use in magic tricks.

The framework optimises artefacts for magical impact in a similar way to systems that use AI techniques to optimise aspects of entertainment in computer gaming. Optimisations have been performed both for elements of games, see Liaw [240], and the overall entertainment value provided by the games, see Yannakakis [241].

In chapters 5 and 6, card tricks of a particular type were examined, and the framework was utilised as both an optimisation and design tool. The use of a mobile phone app, in the case of the Princess card trick, allowed the exploration of the possibility of deploying advanced technologies directly within the performance of a trick, without a reduction in the magical effect experienced by a spectator. The use of such technologies for magic performances was shown to be viable.

The increased responsibilities of a computer in the design process of a magic trick, specifically a card trick, is further explored in this chapter; additionally, a computer is given increased responsibilities during the presentation of a trick, allowing a final investigation into the effect modern technologies can have on the magical impact of certain effects.

8.1.1.1 Ordered decks of playing cards

The use of a pre-ordered deck of cards (known by magicians as a stacked deck) was explored in chapter 6, in the context of the Gilbreath principles. There are many other types of card tricks that rely on different types of pre-ordered decks. The use by magicians of cyclical combinatorial structures in mind reading effects, for example De Bruijn sequences - cyclical sequences of objects in which each unique subsequence of a given length appears once - have been extensively investigated by Chung [33] and Diaconis [30]. There are well known computational algorithms capable of generating particular types of sequences, detailed in Knuth [230], Fredricksen [242] and Stein [243]; these algorithms are generally not configurable to output sequences with particular specified properties, rather they generate orderings of objects with only the property of being De Bruijn sequences (or similar).

Finding cyclical structures such as these, for use in magic tricks, can be a difficult task for a human trick designer: the number of permutations of a deck of 52 standard playing cards is a huge 52 factorial (8×10^{67}). A cyclic sequence of cards is of benefit to a magician during performance, as cutting a deck of cards allows a false sense that the cards have been shuffled (see Hugard [27] for extensive discussion of card shuffling techniques), without disrupting the cyclical order. Unfortunately, for magicians, the riffle shuffle required for a Gilbreath principle based trick disrupts any cyclical structure. However, in the context of magic tricks, cyclical orderings have many benefits of their own.

8.1.1.2 Playing card characteristics

Standard playing cards are of natural interest to magicians, as they form the basis of so many card trick routines. Often, playing cards, and their many permutations, are examined in the context of AI systems for game playing; see Rubin [244] and Frank [245]. The standardised deck of cards widely used allows tricks to be designed that exploit the familiarity of the playing card designs, and further, the relationships between the various suits and values.

The cognitive characteristics of playing cards have been previously studied by Fisher [246]. Recent work by Olson [56] shows that certain cards tend to be liked in preference to others. For example, the picture cards (Jack, Queen, King) and Aces are preferred, along with the Heart and Spade suits. Olson provides an empirically determined likeability index for a standard deck of playing cards: a ranked list describing how likeable each card is.

8.1.1.3 Fishing for information

In many mind reading effects involving playing cards a magician will dispense cards from a pre-ordered deck, and subsequently ask a number of vague innocuous sounding questions to covertly recover the information needed to reveal the card identity, for example: 'are you thinking of a red card?'. This process is referred to by magicians as fishing (discussed in detail in Aronson [247]), magically arriving at a specific, supposedly secret, card while not making it look like they are asking too specific a set of questions. To elicit a magical effect the questions must be perceived as vague and almost inconsequential. The varied approaches to the bank of fishing questions often differentiate the quality and impact of these effects. A classic example is Larson and Wright's Suitability, described in Diaconis [30]: a 52 card deck is ordered in such a way that dealing three consecutive cards from any position in the deck yields a unique set of three Suits. Other orderings can be found such that consecutive cards may be differentiated by multiple categories;

for example, Suits, Colour and Picture Cards. A suitable set of fishing questions then need to be deployed to recover the actual identity.

8.1.1.4 Tree structures for card tricks

These kinds of orderings of card characteristics may be represented as a computational tree structure, defined in Knuth [230], a category at each level determining which tuples (sequences) of cards are placed at which node (branching points), ending in leaf nodes that contain only one tuple of cards of the requisite length. The trick Suitability's tree has only one level beyond the root (the start node), thus requiring only one fishing question per card (which suit it belongs to).

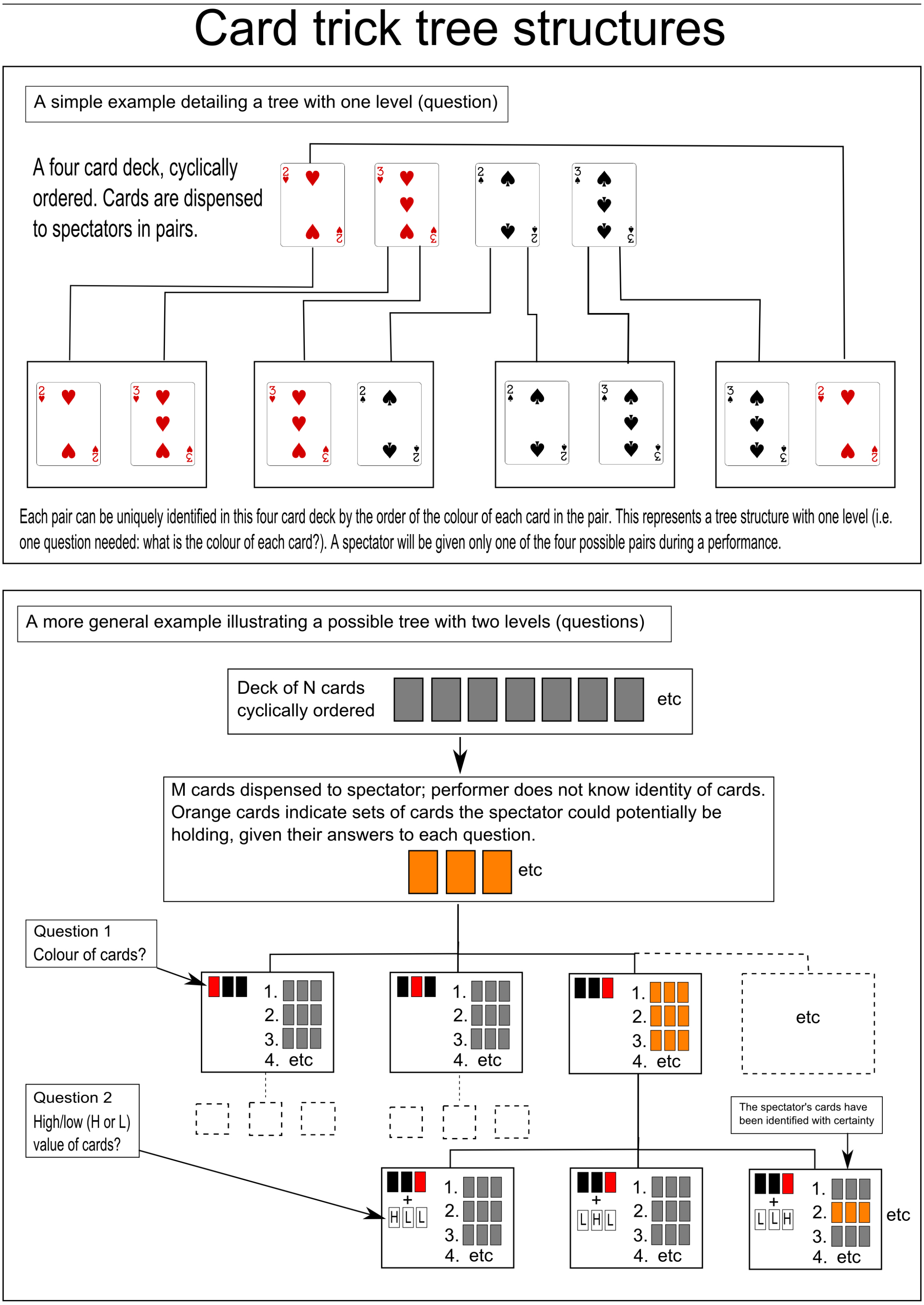
Generally, the shorter the fishing trip of questions is, the more magical the effect. Simon Aronson's trick Simon-Eyes [247] can also be analysed as a tree structure; Simon-Eyes' tree has multiple levels (thus, multiple questions to ask). The pay off is that only two cards need be dispensed to a spectator, and the questions are never met with two negative responses - for example, if the route through the tree leads to an enquiry suggesting one of the dispensed cards is low valued, then at least one of the two cards will be low valued. This allows the performer to make a statement about the two cards that is always true for at least one of them. This is a powerful technique for a magician to deploy, as it builds confidence for the observer that the magician is performing something other than simple question and answer sessions.

Illustrative examples of tree structures of the kind described are shown in 8.1 on page 195.

8.1.1.5 Props

Props have played a vital role in magical effects and illusions for centuries; Christopher and Christopher illustrate numerous examples [1]. Many props are built into a trick in a

Figure 8.1 Simple example of a cyclically ordered card trick tree structure, and a more general structure for trees with more questions.



way that makes them appear innocuous, yet in some way a vital part of the trick. Stage illusions often rely entirely on ingenious prop designs that, while intrinsic to the method behind the effect, operate in a way that does not arouse suspicion in the audience; Mayne [20] describes methods for the construction of these kinds of props. Many commercial card tricks rely on the use of hidden gimmicks, such as cue cards as memory aids - Aronson's Simon-Eyes [247] trick is one example - rather than props which are in full sight of the audience. There is a combinatorial card trick that relies on both the mathematical properties of a deck of cards, and the use of an assistant during presentation; Simonson [248], Kleber [249], and Lee [250] provide detailed discussions.

Memorising a deck of fifty two playing cards is no easy task, even for the dedicated performer. As such, most magic tricks that rely on ordered decks of cards are usually restricted in the orderings that can be used by the mnemonic properties of the sequence of cards. For example, a classic mnemonic aid is to sequence a deck such that the cards follow what is known as a CHaSeD order (Diaconis [30]) - all cards in a deck are ordered: [C]lub, [H]e[a]rt, [S]pad[e], [D]iamond.

8.1.2 The trick [MAGIC]

The designed trick, under investigation throughout this chapter, is a generic tree structure based card trick, outlined above, that relies on a cyclically ordered deck of playing cards. The trick can be performed with many different orderings of cards, each with their own properties; some may require more cards to be dealt from the deck, others less; more cards require less questions to be asked of the spectator to divine the card they have selected. The trick relies on a mobile phone for presentation, that serves as a cognitive aid for the performer (of the type described by Itiel [251]), a queryable memory bank, and as a mysterious way to reveal playing cards at strategic moments. The use of a faked passcode screen is used to allow the performer to pass information to the app about the answers the spectator gives to each question.

Within this structure, there is the difficult problem of the orderings of the deck to solve. We will see how this is tackled in the coming sections.

Noting Olson's [56] work on the likeability of playing cards, discussed above, an additional route to creating engaging magic performances has been added to the type of trick under discussion. The basic tree based trick structure has an added probabilistic element, whereby a spectator is asked to choose their favourite (most liked) card from a group of dealt cards; this decision acts as the answer to a question in the fishing process, based on which the spectator's card can be probabilistically determined.

The spectator's card is revealed to them in the usual manner, but it may take the performer multiple attempts to reveal the correct card, with an increasing probability of success as each failure occurs. The idea that sticks in the spectator's mind is that they had a completely free choice over something that is very specific to them as an individual and somehow the performer was able to divine this choice. This extension is a new avenue to pursue in trick design, with similarities to the inherently risky process involved in the Association trick detailed in chapter 6.

The script and method for the trick are as follows, with minor variations per performance. The particular deck used requires the dealing of four cards to the spectator. The first question asked is about the colour of each card (red or black). The second question in the tree asks the spectator to select their favourite (most liked) card:

Performer (P): "Hello, what's your name?"

Spectator (S): "My name is []"

P: "Nice to meet you. My name is []. I'd like to try something with this deck of cards, if that's OK with you?"

S: "OK"

P: fans out the cards to show S the card faces.

P: "I'll cut the deck at a random place."

P: cuts the deck twice.

P: "Perhaps you'd like to cut the deck?"

P: hands the deck to S, who cuts the deck.

P: "Would you like to cut again?"

S: cuts again if wished.

P: "OK, here we go."

P: takes card off the top of the regular deck and carefully shows the face only to S.

P: "Is this card a red card or a black card?"

S: answers as appropriate.

P: places the playing card face down on the table.

[Repeat for three more cards, building a row of four face down cards]

P: "OK thanks."

P: "Can you please choose your favourite card out of the four on the table. Have a peek at them to remind yourself what they are if you like, just don't show them to me. OK? Pick up your favourite card and keep it in your hand. Don't show it to me."

S: picks up a card.

P: "I'm going to need my phone for this bit."

P: picks up mobile phone. Turns it on to be greeted by a passcode screen. Makes no attempt to conceal this, simply enters in a code as though unlocking the phone. Actually enters information about which cards are red and which card has been chosen. Phone appears to unlock and goes to its home screen.

P: "I've written an app for my phone, that I'm going to use to try to read your mind."

P: finds the app on the phone and opens it. The whole screen displays an animated waveform.

P: "I'm going to put the phone here."

P: places the phone in the space vacated by the spectator's chosen card, completing the row of face down playing cards.

P: “You’ve probably seen magicians on TV doing mind reading effects, people like Derren Brown? [Elaborate as necessary] I’m going to try something similar using my phone to channel your thoughts. Look at your card and picture it in your mind’s eye for me.”

P: as soon as S glances at card, P passes hand over top of mobile phone, triggering the proximity sensor, which in turn triggers an image of the face of a playing card to fade into view [e.g. the Ace of Hearts].

P: “Is this your card?”

P: Looks at phone on table.

If YES, then:

P: “Please place your card face up on the table for all to see...”

If NO, then:

P: “Something must have interfered with the process [elaborate as necessary]...let’s try again, and really try to crystallise that image of the card in your mind...”

[Repeat until the card is displayed on the phone]

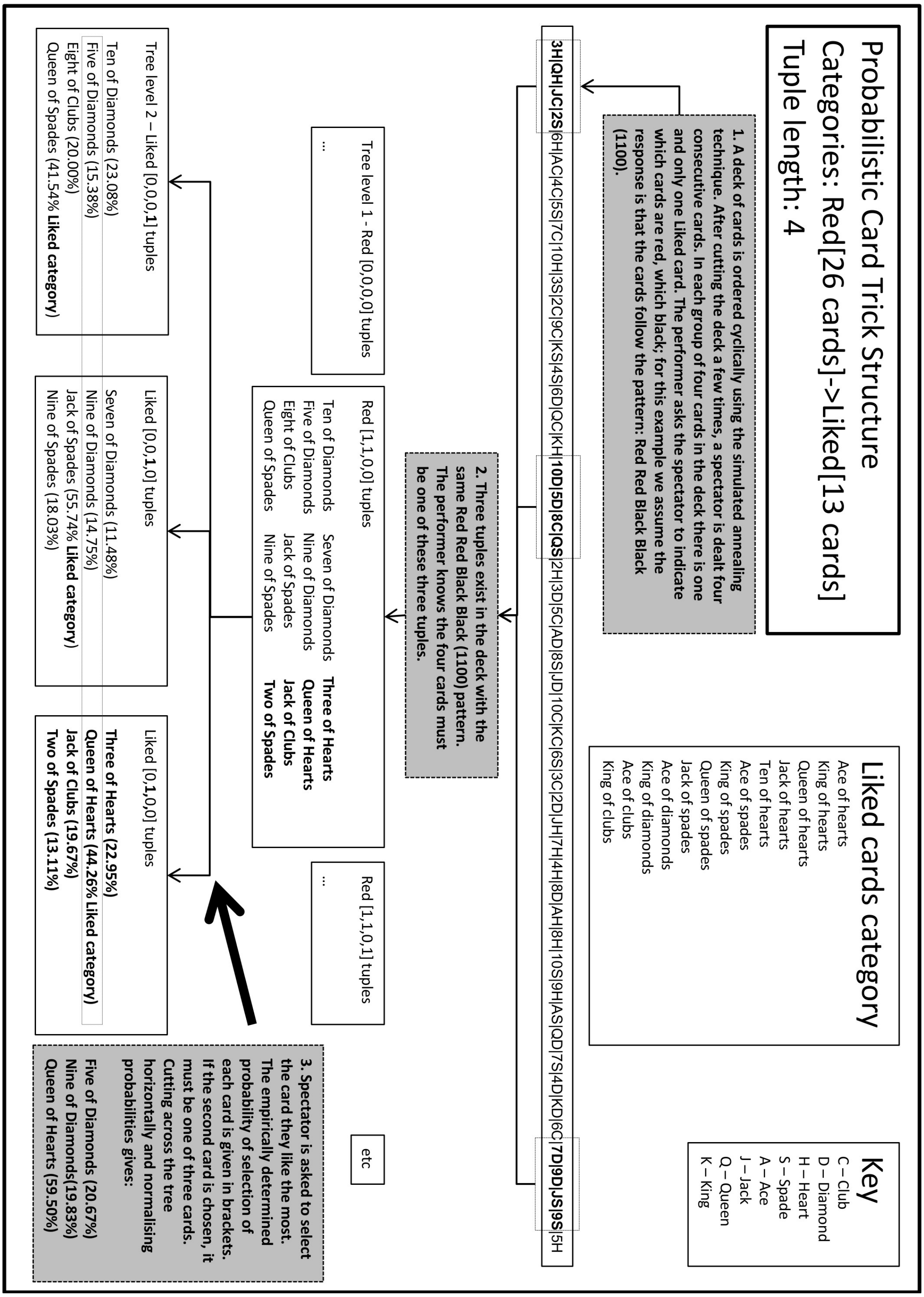
P: “Thanks for taking part.”

The structure of the tree used for the scripted trick above, and how the spectator’s card can be arrived at by the performer, are shown in detail in figure 8.2 on page 200.

8.1.3 Psychological factors [PSYCH])

A major psychological factor involved in the card trick outlined is the spectator’s perception of the information passing mechanism between the performer and the mobile phone. Should the spectator detect that the performer, when supposedly unlocking the phone with the faked passcode, is in fact entering a code that details the answers to the questions posed, then they are likely to discount the entire effect as being a simple information retrieval exercise. The best experiment to perform to determine whether the passcode mechanism is successful or not is to simply perform the trick in the wild.

Figure 8.2 The probabilistic card trick tree structure.



The results of this are detailed in the evaluation section below.

Another psychological factor involved in this kind of trick is whether the spectator feels that the nature of the questions they are asked will inevitably lead the performer to their chosen card. The questions ought to be innocuous, seemingly devoid of enough information to give anything away. There are various techniques deployed by magicians in performance to reduce the sense for the spectator that they are being questioned at all. Aronson [247] provides extensive discussions of these type of issues, recommending that the questions be framed as statements wherever possible. The script for the trick detailed above does not deploy this mechanism, in the interests of clarity. At the point in the script where the performer asks whether each card is a red or a black, a suitable, better, method may be substituted.

Additionally, the number of questions that are asked (i.e. the depth of the tree structure) has an impact on the trick's perception. The less questions there are, the more magical the effect (ideally, though impossibly, no questioning would be required).

Finally, for the probabilistic version of the trick, there is the question of which cards are the most likeable to a spectator. Olson's [56] work, as mentioned, describes a likeability index. This was determined by showing the experimental participants pairs of cards, and asking which they prefer. For the trick described here, there may be a variable number of cards for a participant to choose from, which may have an effect on which card among the group is the most liked. Therefore, Olson's findings were used as a constraint during the generation of new decks, and further experiments, reported later in the chapter, were conducted on the resulting deck, to determine which card in a larger group would be most liked.

The described psychological factors determine what makes a good De Bruijn cycle based card trick for both the performer and the spectator. Table 8-A on page 202 summarises the various factors, and relevant parameters.

The overall flow of the described trick is shown in figure 8.3 on page 203; the unfolding

Psychological factor	**Relevance**	**Parameters**
Detection of the information passing mechanism between the performer and the mobile phone.	Spectator and performer.	1. The mechanism used. 2. The skill of the performer. 3. Any distraction for the spectator.
The spectator's perception of the questioning process.	Spectator and performer.	1. The performance of the questioning. 2. The framing of the questions (e.g. as statements). 3. The number of questions required.
The likeability of the playing cards.	Spectator.	1. The number of cards presented to the spectator to choose from.

Table 8-A: Psychological factors in the card trick.

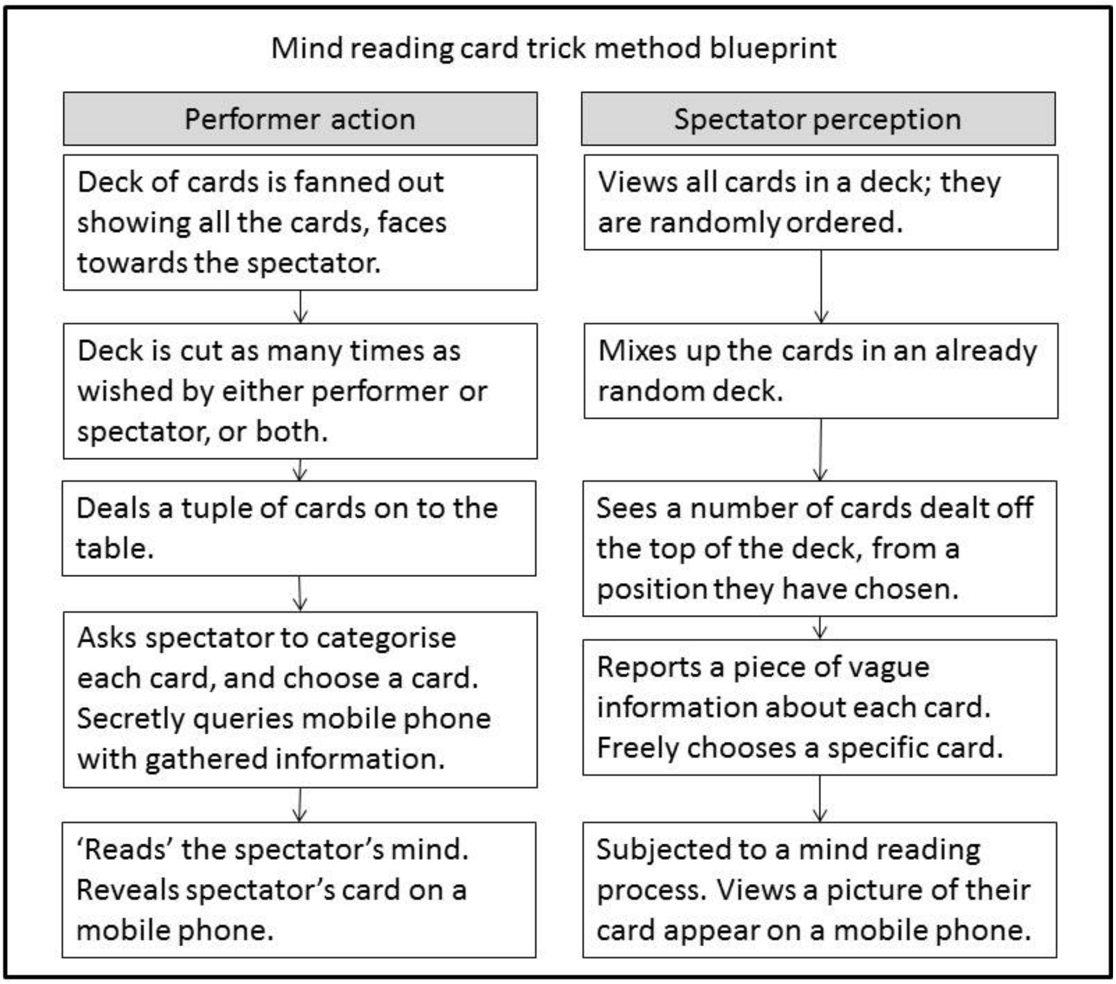
of the trick is shown from the perspective of both the performer and spectator.

8.1.4 Controlled problem domain [DOMAIN]

The generic trick described requires the encoding of a tree based structure representing a cyclically ordered set of playing cards that deconstructs at each level of the tree into a set of cards distinguished by category. Additionally at each leaf node there must be only one set of cards of a given length, and all cards in the deck must be in at least one leaf node.

To encode the card characteristics in a form suitable for the framework, individual cards are allocated a number of categories depending on their features - for example the King of Hearts belongs to the categories: Heart, Red, Picture Card, High Value. The Liked (and Not Liked) category are defined by using the Likeability index, an ordered ranking of how well liked each playing card in a standard deck is when compared to other cards, described by Olson [56].

Figure 8.3 All tree based card tricks can be performed with this structure. Many variations can be imagined.



There are many imaginable ways to categorise playing cards in a standard deck. Stringing these categories together defines the levels in the tree structure. Most are binary categories - a particular playing card either belongs to the category or it doesn't. Hybrid binary categories can easily be defined (e.g. RedHigh defines a card that is both red coloured, and high in value). LowMedHigh and Suit define multi-valued categories - a particular playing card may have one of multiple values from these categories. Below is a list, a kind of menu, of the categories that are defined to create cyclical decks, using varying tuple lengths:

- Suit (Spade, Heart, Diamond or Club)

- Colour (Red or Black)
- Picture (Jack, Queen, King) or Spot (non-picture cards)
- Low (from 2 to 7 inclusive) or High (8 and above, including Aces)
- CurvedIndex or StraightIndex: the text on the face of a card that describes the value can be composed of curvy or straight lines. An 8 is curved, a King (the K on the face of the card) is straight.
- CurvedPip or StraightPip: the pip is the text on the face of the card denoting the suit.
- Liked or NotLiked: cards are drawn from the likeability index reported in Olson [56]
- LowMedHigh: multi-valued category
- Suit: multi-valued category

The various categories that differentiate playing cards (Colour, Suit, etc) can be combined in any way in a single deck, along with the number of consecutive cards that defines a single tuple. Further, additional constraints may be added to cater for specialised orderings or conditions; for example, an additional constraint might be: each tuple at each level in the tree must contain at least one member of the category described at that level (as with the Simon-Eyes trick).

The flexibility of the approach allows for the possibility of the creation of decks to specification, allowing a performer the creative leeway to concentrate on designing an effective presentation that the deck can operate within to maximise a magical effect [10], rather than agonising over the difficult problem of finding a workable ordering of cards.

Table 8-B on page 205 outlines the apparent simplicity of the problem domain of the De Bruijn based card tricks - the ordering of the cards defines the domain - the size of the

Element	**Function**	**Parameter**	**Relevance**	**Design**
The order of the cards.	Defines the tree structure and therefore questions required.	1. The specified categories.	Spectator and performer.	Computer.

Table 8-B: Problem domain parameters for De Bruijn based card tricks.

search space (naively, 52 factorial) makes clear the need for a computer to be deployed as an optimisation method.

8.1.5 Computational technique [AI]

As noted, theoretically, there are 52 factorial (8×10^{67}) ways to order a deck of 52 playing cards. For a computer, there are simply too many possibilities to exhaustively test each ordering. Particularly dedicated humans are able to find decks that can be used in these tree structure based tricks, as noted previously: Larson and Wright's Suitability [30], and Aronson's Simon-Eyes [247] are excellent examples. Finding and evaluating appropriate cyclic orderings is an extremely time consuming process for a human; a task arguably better handled by the search and optimisation engine component of the framework.

There are numerous techniques available for combinatorial optimisation - as seen in the previous chapter, GAs are useful for large search spaces, where traditional search techniques are not feasible. The problem under consideration here is again intractable for traditional exhaustive searches due to the huge number of combinations of cards possible in a fifty two card deck. In some senses, GAs are best applied where no other optimisation technique appears to be able to provide a good solution in a reasonable time, as they are able to contend with search spaces that are of an unknown character - therefore, the GA can be configured and applied without a detailed investigation being performed as to the shape of the state space that it will search. Here, for the orderings of playing cards, the search space is better defined, and less complex (though not smaller) in character.

8.1.5.1 Simulated Annealing

Simulated annealing (SA) is a probabilistic search technique based on a metallurgical technique, annealing, whereby substances are heated to high temperatures and then cooled in a controlled way allowing them to settle to a low-energy crystalline state. In computing, SA works by combining notions of hill climbing and random walks through state spaces. SA is often used for discrete search spaces [110].

SA was selected as an appropriate technique for the framework's search and optimisation engine in this instance as it has been shown to perform well in related search tasks such as the 8-Queens problem (described in Russell [110]). Applying a GA, or other optimisation technique, would likely provide solutions, but it is estimated that applying a SA procedure in this instance is more suitable, given the prior success of previous applications of it to similar problems with similar state spaces.

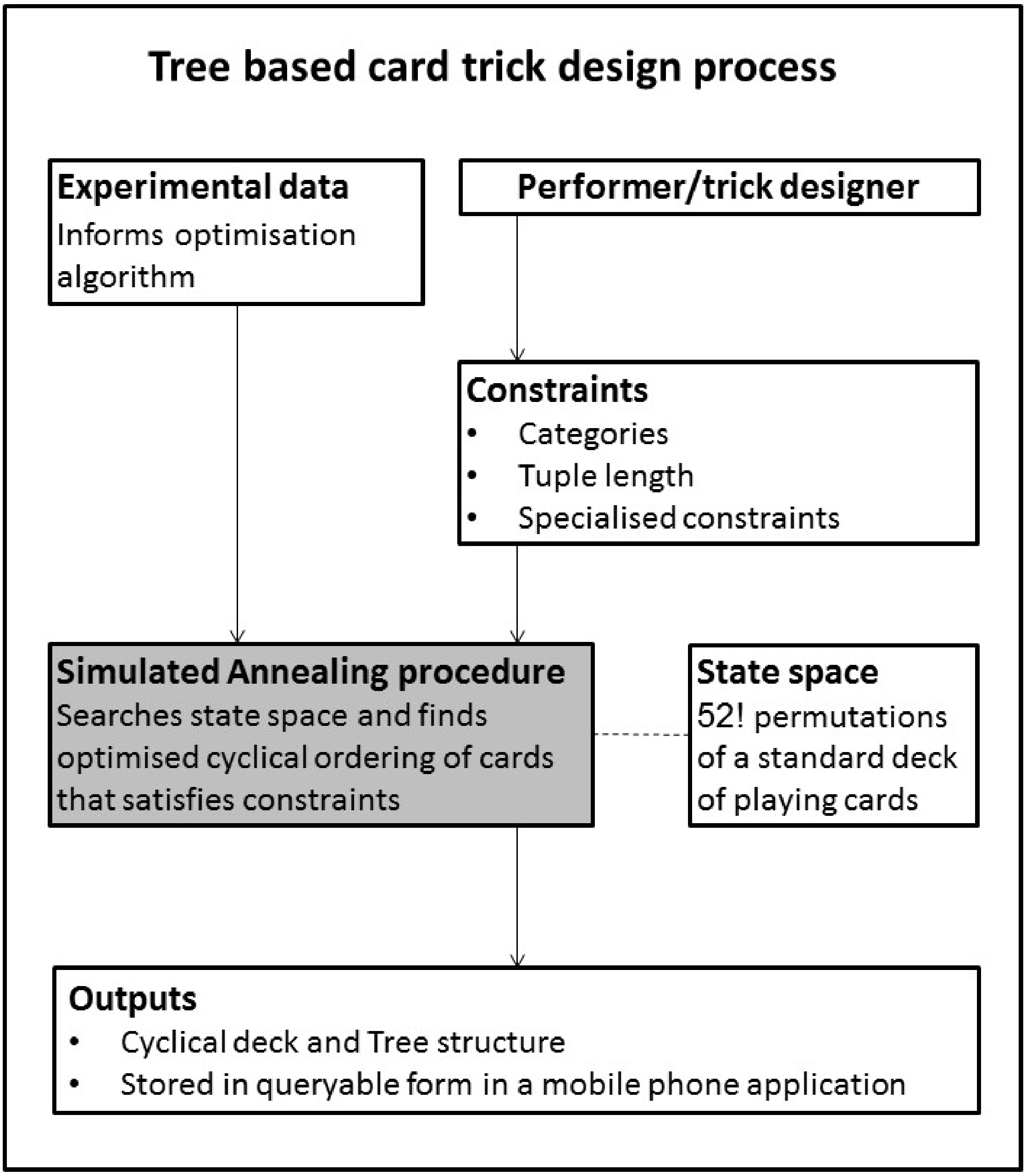
Here, a SA procedure configured with user defined parameters, to search for entertaining, or magical, combinatorial structures to be used in playing card tricks, is described.

8.1.5.2 The card trick algorithm

The basic function of the SA procedure is to operate on a list of playing cards, swapping card positions to re-order the deck over many iterations, in order to maximise the longest consecutive sequence of cards that contains non-repeating sub-sequences of a specified length that uniquely identify themselves in the deck by the order of their categories (in the context of which level in the tree structure they are). A fifty two card cycle is the theoretical maximum for a fifty two card deck. As there may be more than one valid cycle for each set of categories selected, additional heuristics may be used to guide specific (not categorical) card placements, depending on the type of deck sought.

See figure 8.4 on page 207 for an overview of the framework process as applied to designing mind reading card trick effects of the kind described in this chapter.

Figure 8.4 Flexible design system for designing mind reading card tricks based on cyclical decks.



8.1.5.3 The card trick algorithm computation time

The implemented procedure is described by the algorithms detailed in appendix D on page 276. The procedure finds solutions, where they exist, in roughly fifteen to thirty minutes (depending on the annealing schedule used) running on a desktop PC with an Intel Core i5 processor.

8.1.5.4 Evaluating tree structures

Different orderings of cards result in different tree structures of variable quality, depending on their maximum and average depths (related directly to the number of questions required to traverse from the root to a leaf node).

To evaluate the depth properties of the optimised decks produced by the system, it was put to work constructing a deck that could be used as a replacement in an existing trick. Simon Aronson's Simon-Eyes [247] effect, detailed above, was selected. On average, in Aronson's deck, 4.04 questions will need to be asked to arrive at a specific tuple of length two. Using the SA based procedure detailed, a deck also using two cards, with a different set of categories, has been found that, on average, will require 3.88 questions. Both decks require a minimum of three questions, and a maximum of five. It is important to note that the deck with improved average depth properties relies on the use of a mobile phone application to do the memory work, that Aronson's ingenious deck does not require, though Aronson does recommend the use of a cue card.

8.1.5.5 A probabilistic extension with magical potential

The magical potential of an ordering that also relies on the Likeability of certain cards introduces an interesting probabilistic perspective - people are more likely to choose well liked cards in a presented set, but this choice is not guaranteed. However, having those Liked cards in otherwise standard tuples should bias the likelihood of their selection, which can lead to a reduction in fishing questions needed. Therefore, the positioning of Liked cards throughout the cyclic deck becomes an additional constraint to optimise.

Using the SA technique described, a deck was constructed to test and optimise the various properties of the probabilistic trick based on the Liked category. Using the raw likeability index described by Olson, a deck was specified that has two categories, and a tuple length of four. The categories used were Red, and Liked. For the following discussion, cards are described using the following key:

[A:Ace, K:King, Q:Queen, J:Jack, ♣:Club, ♢:Diamond, ♡:Heart, ♠:Spade]

The thirteen cards contained in the Liked category were the thirteen highest ranked cards from Olson's likeability index, in rank order:

$$A\heartsuit, A\spadesuit, K\heartsuit, Q\heartsuit, 2\heartsuit, J\heartsuit, J\spadesuit, Q\spadesuit, 2\spadesuit, 6\heartsuit, 10\heartsuit, K\spadesuit, A\clubsuit$$

An additional constraint was added to the search process: each tuple must contain one and only one Liked card. Thus, during the trick, any four cards dealt from the deck will result in just one Liked card being available. This is the most likely card for a spectator to pick when asked to select their favourite (or, most liked) card.

The search process found the following deck, named **LikeableDeck1**:

$$10\spadesuit, A\diamondsuit, A\spadesuit, 5\heartsuit, 9\spadesuit, 8\heartsuit, A\heartsuit, Q\clubsuit, 3\heartsuit, K\diamondsuit, K\heartsuit, 9\diamondsuit, 5\clubsuit, 8\diamondsuit, 2\spadesuit, 7\clubsuit, 6\clubsuit,$$
$$2\diamondsuit, 6\heartsuit, 7\diamondsuit, 7\heartsuit, 4\clubsuit, A\clubsuit, 3\clubsuit, 4\spadesuit, 6\spadesuit, 10\heartsuit, K\clubsuit, 4\diamondsuit, 8\spadesuit, Q\heartsuit, 9\heartsuit, 10\diamondsuit, 5\diamondsuit, 2\heartsuit,$$
$$10\clubsuit, 5\spadesuit, 8\clubsuit, Q\spadesuit, Q\diamondsuit, 3\spadesuit, 7\spadesuit, J\spadesuit, 9\clubsuit, 6\diamondsuit, 4\heartsuit, K\spadesuit, 3\diamondsuit, J\diamondsuit, 2\clubsuit, J\heartsuit, J\clubsuit$$

An online experiment was then conducted, during which participants (N=54) were shown each tuple of four cards from the deck (i.e. fifty two screens), and asked to click on the card they liked the most. The participant group featured 29 males and 25 females. 19 respondents were from America, 30 from Northern Europe, 3 from Canada, 1 from India, and 1 from Australia. Ages ranged from 18 to 69, approximately normally distributed.

8.1.5.6 Optimising the magic of chance

From the results of the experiment on LikeableDeck1, detailed in figure 8.5 on page 220, it became apparent that there were a number of tuples for which the most popular choice of Liked card differed to the predicted card based on the Olson data.

The assumption is that this difference in the apparent likeability of certain cards is due to using four cards, rather than two, in the experiment presented here; i.e. the effects of the three other cards on the predicted Liked card's likeability. While Olson produced a multi-purpose index of likeability for each individual card in a deck, using a methodology of presenting cards in pairs to observers for comparison, the data produced and used here is predicated on the idea of tailoring an experiment to a particular trick - the goal being to use the data produced as a source to inform the best way to arrange a deck for use in the trick. Thus, that there were difference is not unexpected, though the particular differences were of interest. Eight tuples, including those containing the Two of Hearts, the Two of Spades, and the Six of Hearts, produced results different from those predicted.

Based on these observations, the rankings of the likeable cards were altered to instead reflect the general advice for magicians given by Olson about which cards people generally like the most, but discarding the gender specific results:

> People like:
>
> - Hearts
> - Spades
> - Aces
> - Face cards
>
> Also, women seem to prefer lower-valued cards (Twos and Threes) more than men do. [56]

So, the thirteen Liked cards became, in rank order:

$$A\heartsuit, A\spadesuit, K\heartsuit, Q\heartsuit, J\heartsuit, K\spadesuit, 10\heartsuit, Q\spadesuit, J\spadesuit, A\diamondsuit, K\diamondsuit, A\clubsuit, K\clubsuit$$

The challenge was to identify rules that maximised the chances of someone picking the predicted Liked cards based on the other three cards in the group. Some general heuristic rules were designed to maximise this probability. These rules, given to the optimiser, were:

- Maximise the distance between the rank in the Likeability index of the Liked card in the tuple, and the highest rank from the other cards.
- Minimise the number of hearts in any one tuple.
- For Liked clubs (i.e. the Ace of Clubs and the King of Clubs) minimise the number of red cards in the same tuple.
- Minimise the number of cards in tuples that are of higher value than the Liked card.

The search process found the following optimised deck, named **LikeableDeck2**:

$3\heartsuit, Q\heartsuit, J\clubsuit, 2\spadesuit, 6\heartsuit, A\clubsuit, 4\clubsuit, 5\spadesuit, 7\clubsuit, 10\heartsuit, 3\spadesuit, 2\clubsuit, 9\clubsuit, K\spadesuit, 4\spadesuit, 6\diamondsuit, Q\clubsuit,$
$K\heartsuit, 10\diamondsuit, 5\diamondsuit, 8\clubsuit, Q\spadesuit, 2\heartsuit, 3\diamondsuit, 5\clubsuit, A\diamondsuit, 8\spadesuit, J\diamondsuit, 10\clubsuit, K\clubsuit, 6\spadesuit, 3\clubsuit, 2\diamondsuit, J\heartsuit,$
$7\heartsuit, 4\heartsuit, 8\diamondsuit, A\heartsuit, 8\heartsuit, 10\spadesuit, 9\heartsuit, A\spadesuit, Q\diamondsuit, 7\spadesuit, 4\diamondsuit, K\diamondsuit, 6\clubsuit, 7\diamondsuit, 9\diamondsuit, J\spadesuit, 9\spadesuit, 5\heartsuit$

8.1.5.7 Optimisation results

A final online experiment was performed with this new deck during which participants (N=69, a similarly representative sample, as previously) were again shown each tuple of four cards from the deck (this time, using LikeableDeck2), and asked to click on the card they liked the most. This deck gave better matches between the predicted Liked card in any given tuple and the actual most liked card. The most liked card did not match the predicted most liked card for only one tuple, contrasting with eight in LikeableDeck1. This tuple is composed of: Eight of spades, Jack of diamonds (actual most liked card), Ten of clubs, King of clubs (predicted most liked).

Figure 8.6 on page 221 shows the full results from the testing of the improved deck.

The outlined optimisation process has shown that the framework is able to perform iteration loops, in order to optimise magical effects. Existing psychological data describing the likeability of playing cards has been integrated into the search process. The output of an initial search has then been subjected to further empirical investigation, before the algorithm has been configured with new heuristics to reflect the new data, resulting in a further optimised deck of cards available for use directly in a magic trick.

8.1.6 Technology [TECH]

As discussed, the tree based card tricks under discussion in this section rely on ordered decks of playing cards that are difficult to memorise for performers. Existing effects sometimes rely on physical cue cards that a magician may secretly consult during performance. Mnemonics are also used; specific orderings that contain some kind of memorable structure, to aid recall.

Instead, a mobile phone may be used, as illustrated in the script for the trick above. The app itself is a custom designed app, named **Phoney**, that functions as both a queryable memory bank, and as a method of presenting the spectator's chosen card. Thus, the particular deck loaded into the memory bank may be queried by the performer, using information gleaned from the spectator during the trick.

A faked passcode screen is used as the information passing mechanism. The performer determines from the spectator the necessary information about the categories each dispensed card belongs to, and asks them to select one specific card. From this data, the performer constructs a code that represents the categories, and the spectator's choice.

The exact nature of the code depends on the categories used, but generally follows the format: [XXXY], where an X represents some information about a single card's category, while Y represents the number of the card chosen. For example, using a deck that has two categories (i.e. two questions), Red, and Liked, the performer must first find out which of the dealt cards are red. Let three of the four cards be red, at positions 1, 3, and 4, counting from the left, from the perspective of the performer. The spectator then selects card number 2, using the same counting system. The code in this scenario is: [1342].

This code is entered into the passcode screen, under the illusion that it is to unlock the phone. Once entered, the tree structure stored in the phone is queried, and the specific card the spectator has chosen is determined. The phone appears to unlock, and displays the operating system's home screen. The performer can then open the app. The face of the spectator's card can then be revealed by the performer; as with the Crystal Ball trick detailed in chapter 6, the proximity sensor on the phone is deployed, enabling the performer to simply pass their hand over the phone, to initiate a short fade in of the image of the face of the card.

The Phoney app is pre-loaded with three different decks:

1. Requires the dealing of six cards to a spectator, with one question about the colour of the cards. The spectator then selects any card, which can be revealed.

2. Requires the dealing of four cards to a spectator, with one question about the value range of the cards (whether each card is low, medium, or high valued). The spectator then selects any card, which can be revealed.

3. Requires the dealing of four cards, with one question about the colour of the cards. The spectator is then asked to select their favourite (most liked) card, which can be revealed with a certain probability of success. After three failed attempts, the fourth is guaranteed to be successful.

See figure 8.7 on page 222 for a visual walk-through of the Phoney trick.

While the app discussed in chapter 6, the Crystal Ball trick, made efforts to conceal the fact that the performer was passing information to the phone, the implementation of Phoney attempts to eradicate this entirely. Passcode screens are widely used by owners of mobile phones, and are subsequently not necessarily an inherently suspicious presence in a trick. This, combined with the queryable nature of the technology used for Phoney, means that a performer is able carry an almost self working trick around with them in their pocket, that requires only that they remember the simple rules to construct a passcode, and the overall format of the trick.

Whether the passcode method of information passing indeed becomes essentially invisible to an audience is explored in the following evaluation section.

8.1.7 Evaluation [EVAL]

To determine the efficacy of the mobile phone app, Phoney, and by extension the trick itself, an experiment was conducted at a science fair - Big Bang 2013, at the NEC in Birmingham, UK - where a particular version of the trick was performed for random spectators (N=116). The Liked card deck, LikeableDeck2, described above, was used. The experiment allowed the determination of how suspicious participants were of the mobile phone and its capabilities during a magic performance (and how this might affect their enjoyment of the trick), and also how robust the most liked card predictions, optimised specifically for the trick, proved to be in a real world scenario. The magical effect of the app was empirically evaluated, and compared to the ratings from those gathered for the classic magic tricks (N=96, results reported in section 4.2.6.1 on page 77).

The participants in the card trick experiment were asked to indicate how much, in general, they enjoy magic tricks (on an ascending enjoyment scale of 0 to 4, mapped to the phrases ‘Hate them!’, ‘Dislike them’, ‘Neutral’, ‘Like them’, ‘Love them!’), and also how much they enjoyed this particular trick (the same scale). They were also asked to choose any number of words from a list that they felt reflected their reaction to the trick; this list: Bored, Surprised, Obvious, Neutral, Impressed, Predictable, Amazed. They were asked to write freely about any moments in the trick when they felt something suspicious might be happening. Similarly, they were asked to write freely about how they thought the trick worked.

The average (mean) rating given to the trick was 3.28 (out of 4). The average (mean) rating given to participants' general view of magic was 3.53. The calibrated average (mean) was 3.04. It is interesting to note that this trick scored higher than both the magic jigsaw and the classic tricks discussed earlier. However, the participant's general rating of magic was also higher. This can possibly be attributed to the fact that the card trick was performed in a live setting, rather than in an online experiment, and that people choosing to sit down to see a trick were more likely to enjoy magic. The online participants may have been a more varied group (in terms of enjoying magic). The difference between the general rating and the card trick rating is 0.25 (this is similar to the jigsaw's difference rating of 0.24).

Table 8-C on page 216 summarises the results. A one-way between subjects ANOVA was conducted to compare the effect of trick on enjoyment rating for tricks in Princess, Association, Crystal Ball, Jigsaw, and Phoney conditions. There was a significant effect of trick on enjoyment rating at the $p < 0.05$ level for the five conditions [$F(4, 327) = 11.69$, $p < 0.01$]. Post hoc comparisons using the Tukey HSD test show that there was a significant difference between the Jigsaw (M=2.44, SD=0.96) and each of the the other four conditions, Princess (M=3.58, SD=0.51), Association (M=3.27, SD=0.64), Crystal Ball (M=3.50, SD=0.68), and Phoney (M=3.28, SD=0.70), but no significant differences within the other four.

Trick	**Mean enjoyment score reported for the trick**	**Mean enjoyment score reported for magic in general**	**Difference**
Princess card trick	3.58	3.79	0.21
Association trick	3.27	3.50	0.23
Crystal Ball trick	3.50	3.52	0.02
Jigsaw trick	2.44	2.68	0.24
Phoney (card trick)	3.28	3.53	0.25

Table 8-C: Summary of enjoyment scores reported by groups viewing each trick. Lower Difference scores are better.

The words chosen by the participants, from the distilled list, to describe the card trick, were overwhelmingly favourable. Participants were asked to circle at least one word from the list; some circled more. Of 164 words reported, 36 were ‘Surprised’, 47 ‘Amazed’, and 61 ‘Impressed’.

The free writing component of the evaluation allows participants to describe how the trick works, and to report any suspicious moments during performance. No participants were able to fully describe the operation of the trick. Approximately 10% guessed that the method relied on the ratio of red and black cards on the table. A small number of participants (2) reported that the trick must work using a pre-ordered deck (which is correct, but could be easily mitigated by a professional magician skilled in more sophisticated false shuffles).

No participants made mention of the passcode as either a suspicious event or as part of the working of the trick. Other events during the trick were suspected more than the passcode; for example, the cutting of the cards, and the overall handling of the cards by the performer. Most often, the spectator had no theory for how the trick worked.

Approximately 25% of participants reported that the phone must be involved somehow (it did, after all, reveal their card to them), but could not give a theory explaining its role. A few vague theories were posited, such as tapping the phone to produce the card, or hovering a hand over the phone. A few more outlandish theories were suggested - most notably: soundwaves, actual mind reading by the phone, and heat imprints from the table. A small number of participants made plausible guesses at the method (RF tags embedded in the cards, or that the entire deck had been memorised by the performer), but usually these explanations had not spoiled their enjoyment of the trick, suggesting that they were not wholly convinced they had correctly deduced the method.

During this probabilistic version of the trick it is inevitable that sometimes the wrong card will appear on the phone initially; it may take up to four attempts to reveal the correct card. Surprisingly, this had little effect on the enjoyment rating of the trick, though on the odd occasion that the full four attempts were taken, there was a reduction in the rating of enjoyment score reported. Otherwise, it is relatively easy for the performer to explain away the failures. For example, the magician might explain away a failure by saying that very advanced mind reading technology is being used, therefore naturally sometimes there are errors, and that they should try again, but this time the spectator must make a more concerted effort to visualise their card in their mind.

8.1.8 Validation [VALID]

The Phoney mobile phone app that enables the presentation of the trick using various different decks with differing properties was successfully sold to magicians via a reputable magic shop, Davenports, in London, UK, at £0.99, a price comparable to other apps. The app has recently been released on the Google Play store, and at the time of writing has sold 484 copies, after receiving a degree of press attention (to be discussed further in the Conclusions in chapter 9). Thirteen reviews have been posted, seven awarding five stars out of five, along with a review comment, from a magician: “Absolutely Brilliant”.

The product continues to be available for sale. Each additional sale provides further concrete evidence that the framework process has successfully output an optimised, novel trick, of interest to its target audience.

8.1.9 Conclusions from the tree based card trick

In this chapter, the design and optimisation of a tree structure based card trick has been described, utilising all components of the proposed framework. A mobile phone app, Phoney, was shown to be an effective presentation device, acting as a gimmicked prop. An iterative optimisation process was followed to create a specific ordering of a deck of playing cards that allows a performer to probabilistically determine a spectator's choice based on observed cognitive characteristics of playing cards.

The SA based [110] search method presented can design cyclically ordered decks of playing cards that can be used in any card trick of an identified generalised type. A large number of magical effects are based on cyclical decks of this nature [30]. The system allows a user to specify the type of categories and number of cards to be used, and finds a solution if there is one available. Additional constraints can be added for further specialising the decks.

An empirical investigation has been performed of the introduction of a probabilistic element to card tricks of this type, based on the cognitive characteristics of certain playing cards [56]. The probabilistic extension to this generalised type of trick shown here can be further exploited in the future to design even more magical and seemingly impossible tricks. The use of a probabilistic mechanism allows both a reduction in the amount of information that needs to be gleaned from a spectator, while making plain that genuine free choice is involved based on subjective preference, leading to a stronger magical effect. Reducing the chance of failure by the performer and enhancing the experience of magical events for the audience can therefore be closely tied together.

An empirical investigation has also been performed into the use of a mobile phone in the tricks presented where the device is intrinsic to the working of the trick, yet plays the role of merely a prop. It has been shown that the phone as a cognitive aid to the performer can be used in plain sight, yet unnoticed, when deployed in the right context. A major issue with the use of technology in a magic trick is that it gives the spectator an easy explanation for what has occurred, which can greatly reduce the overall effect. The successful introduction of everyday technology into the trick described in this chapter has circumvented this; it seems the key is that the device is used in a way that is so familiar, a passcode to unlock a phone, that it effectively becomes psychologically invisible to the spectator. As a result, using the phone to reveal a card the spectator has chosen is essentially inexplicable as the actual method used is not available to them when attempting to mentally reconstruct the trick. While advanced technology can often appear magical in operation, actual magic tricks must never appear simply technological in performance; using technology in plain sight helps produce a genuinely magical effect.

The role of the computer, in the work described in this chapter, is at the core of both the design of the artefact (the decks of cards), and the presentation of the trick (Phoney). Psychological constraints, based on empirically sourced data, integrated into the operation of the AI technique are similarly vital. All the framework's components have been shown working in conjunction, and each exploited fully, in the design, optimisation, evaluation, and validation of a novel magic trick.

8.2 Summary

In this chapter the framework has been shown to be capable of using an automated AI system to design optimally ordered decks of playing cards for use in real world magic tricks. A new type of magic trick has been shown that relies on experimentally derived probabilities of spectator selections. A mobile phone has been shown to be capable of operating as a presentation device and a gimmicked prop during a magic trick. The framework approach has been shown as a fully developed integration methodology for creating and optimising new magic tricks.

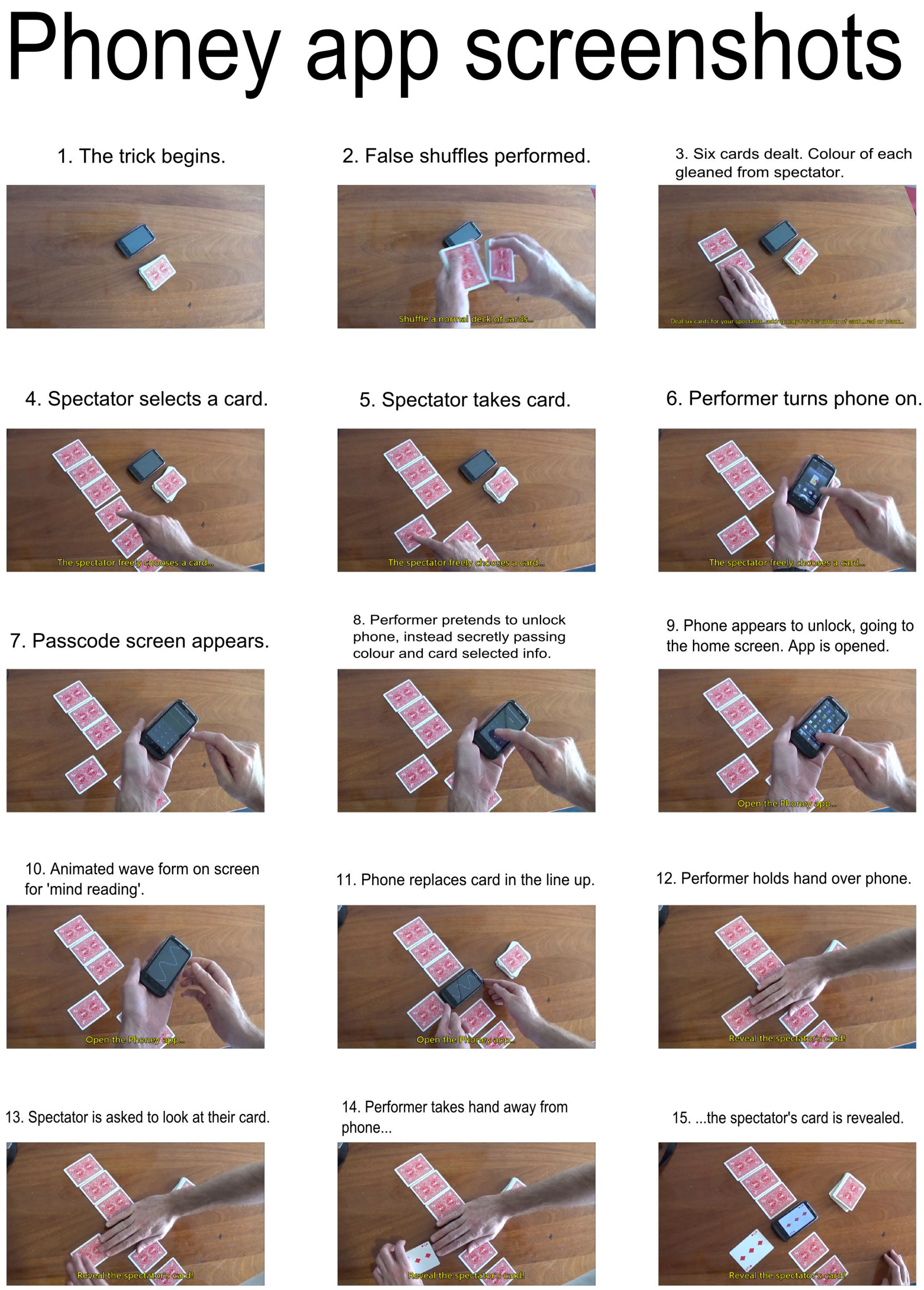
Figure 8.5 The data from the likeable card experiment performed using LikeableDeck1; a deck with tuple length 4. Participants were asked to select favourite cards from groups of four. Eight of these tuples resulted in the most liked card differing from that predicted by the Olson model. These are shown highlighed in orange.

Tuple				Outcome	
Card 1 (liked percent)	Card 2 (liked percent)	Card 3 (liked percent)	Card 4 (liked percent)	Most liked	Predicted
eight_heart (10.53)	ace_heart (68.42)	queen_club (10.53)	three_heart (10.53)	ace_heart	ace_heart
seven_heart (17.5)	four_club (7.5)	ace_club (62.5)	three_club (12.5)	ace_club	ace_club
four_club (4.76)	ace_club (61.9)	three_club (19.05)	four_spade (14.29)	ace_club	ace_club
nine_spade (4.88)	eight_heart (21.95)	ace_heart (60.98)	queen_club (12.2)	ace_heart	ace_heart
ace_diamond (17.07)	ace_spade (60.98)	five_heart (17.07)	nine_spade (4.88)	ace_spade	ace_spade
ace_heart (57.89)	queen_club (15.79)	three_heart (10.53)	king_diamond (15.79)	ace_heart	ace_heart
ace_club (57.14)	three_club (19.05)	four_spade (16.67)	six_spade (7.14)	ace_club	ace_club
five_heart (9.76)	nine_spade (19.51)	eight_heart (14.63)	ace_heart (56.1)	ace_heart	ace_heart
ace_spade (56.1)	five_heart (17.07)	nine_spade (9.76)	eight_heart (17.07)	ace_spade	ace_spade
three_spade (17.5)	seven_spade (15)	jack_spade (55)	nine_club (12.5)	jack_spade	jack_spade
three_club (15)	four_spade (12.5)	six_spade (17.5)	ten_heart (55)	ten_heart	ten_heart
seven_diamond (7.69)	seven_heart (28.21)	four_club (10.26)	ace_club (53.85)	ace_club	ace_club
seven_spade (12.82)	jack_spade (53.85)	nine_club (12.82)	six_diamond (20.51)	jack_spade	jack_spade
queen_heart (52.27)	nine_heart (20.45)	ten_diamond (15.91)	five_diamond (11.36)	queen_heart	queen_heart
jack_spade (50)	nine_club (16.67)	six_diamond (19.05)	four_heart (14.29)	jack_spade	jack_spade
ten_spade (7.5)	ace_diamond (27.5)	ace_spade (47.5)	five_heart (17.5)	ace_spade	ace_spade
jack_club (7.5)	ten_spade (20)	ace_diamond (25)	ace_spade (47.5)	ace_spade	ace_spade
four_heart (17.07)	king_spade (46.34)	three_diamond (21.95)	jack_diamond (14.63)	king_spade	king_spade
king_diamond (19.51)	king_heart (46.34)	nine_diamond (24.39)	five_club (9.76)	king_heart	king_heart
six_diamond (7.5)	four_heart (25)	king_spade (45)	three_diamond (22.5)	king_spade	king_spade
jack_diamond (18.6)	two_club (25.58)	jack_heart (44.19)	jack_club (11.63)	jack_heart	jack_heart
two_diamond (27.5)	six_heart (42.5)	seven_diamond (7.5)	seven_heart (22.5)	six_heart	six_heart
queen_diamond (26.32)	three_spade (21.05)	seven_spade (10.53)	jack_spade (42.11)	jack_spade	jack_spade
ten_club (21.05)	five_spade (21.05)	eight_club (15.79)	queen_spade (42.11)	queen_spade	queen_spade
queen_club (9.3)	three_heart (27.91)	king_diamond (20.93)	king_heart (41.86)	king_heart	king_heart
queen_spade (41.03)	queen_diamond (23.08)	three_spade (23.08)	seven_spade (12.82)	queen_spade	queen_spade
king_heart (40.48)	nine_diamond (21.43)	five_club (16.67)	eight_diamond (21.43)	king_heart	king_heart
four_diamond (17.5)	eight_spade (22.5)	queen_heart (40)	nine_heart (20)	queen_heart	queen_heart
two_club (12.5)	jack_heart (40)	jack_club (15)	ten_spade (32.5)	jack_heart	jack_heart
six_club (11.63)	two_diamond (23.26)	six_heart (39.53)	seven_diamond (25.58)	six_heart	six_heart
two_spade (39.53)	seven_club (20.93)	six_club (13.95)	two_diamond (25.58)	two_spade	two_spade
ten_diamond (33.33)	five_diamond (12.82)	two_heart (38.46)	ten_club (15.38)	two_heart	two_heart
five_spade (17.95)	eight_club (20.51)	queen_spade (38.46)	queen_diamond (23.08)	queen_spade	queen_spade
three_diamond (25)	jack_diamond (17.5)	two_club (20)	jack_heart (37.5)	jack_heart	jack_heart
nine_diamond (25)	five_club (17.5)	eight_diamond (20)	two_spade (37.5)	two_spade	two_spade
nine_club (20)	six_diamond (17.5)	four_heart (25)	king_spade (37.5)	king_spade	king_spade
three_heart (26.83)	king_diamond (17.07)	king_heart (36.59)	nine_diamond (19.51)	king_heart	king_heart
seven_club (30.77)	six_club (12.82)	two_diamond (20.51)	six_heart (35.9)	six_heart	six_heart
king_spade (35.9)	three_diamond (25.64)	jack_diamond (17.95)	two_club (20.51)	king_spade	king_spade
eight_spade (20.51)	queen_heart (35.9)	nine_heart (28.21)	ten_diamond (15.38)	queen_heart	queen_heart
five_diamond (25.64)	two_heart (35.9)	ten_club (20.51)	five_spade (17.95)	two_heart	two_heart
two_heart (34.15)	ten_club (21.95)	five_spade (26.83)	eight_club (17.07)	two_heart	two_heart
eight_club (18.18)	queen_spade (31.82)	queen_diamond (27.27)	three_spade (22.73)	queen_spade	queen_spade
king_club (25.58)	four_diamond (23.26)	eight_spade (23.26)	queen_heart (27.91)	queen_heart	queen_heart
eight_diamond (47.5)	two_spade (32.5)	seven_club (10)	six_club (10)	eight_diamond	two_spade
jack_heart (23.81)	jack_club (19.05)	ten_spade (14.29)	ace_diamond (42.86)	ace_diamond	jack_heart
five_club (12.5)	eight_diamond (42.5)	two_spade (37.5)	seven_club (7.5)	eight_diamond	two_spade
four_spade (9.52)	six_spade (14.29)	ten_heart (35.71)	king_club (40.48)	king_club	ten_heart
nine_heart (25.58)	ten_diamond (39.53)	five_diamond (6.98)	two_heart (27.91)	ten_diamond	two_heart
six_spade (12.5)	ten_heart (30)	king_club (35)	four_diamond (22.5)	king_club	ten_heart
six_heart (17.5)	seven_diamond (32.5)	seven_heart (32.5)	four_club (17.5)	seven_diamond	six_heart
ten_heart (25)	king_club (32.5)	four_diamond (25)	eight_spade (17.5)	king_club	ten_heart

Figure 8.6 The data from the likeable card experiment performed using LikeableDeck2, with tuple length 4. Participants were asked to select favourite cards from groups of four. Only one tuple differed from the predicted most liked outcome, in constrast to 8 differences when LikeableDeck1 was used.

Tuple				Outcome	
Card 1 (liked percent)	Card 2 (liked percent)	Card 3 (liked percent)	Card 4 (liked percent)	Most liked	Predicted
four_heart (8.45)	eight_diamond (7.04)	ace_heart (74.65)	eight_heart (9.86)	ace_heart	ace_heart
ace_spade (68.92)	queen_diamond (14.86)	seven_spade (9.46)	four_diamond (6.76)	ace_spade	ace_spade
two_heart (10)	three_diamond (10)	five_club (11.43)	ace_diamond (68.57)	ace_diamond	ace_diamond
ace_heart (64.29)	eight_heart (12.86)	ten_spade (14.29)	nine_heart (8.57)	ace_heart	ace_heart
eight_diamond (9.86)	ace_heart (63.38)	eight_heart (14.08)	ten_spade (12.68)	ace_heart	ace_heart
three_diamond (19.44)	five_club (9.72)	ace_diamond (62.5)	eight_spade (8.33)	ace_diamond	ace_diamond
seven_heart (18.84)	four_heart (10.14)	eight_diamond (8.7)	ace_heart (62.32)	ace_heart	ace_heart
eight_heart (11.76)	ten_spade (13.24)	nine_heart (14.71)	ace_spade (60.29)	ace_spade	ace_spade
five_club (16.44)	ace_diamond (60.27)	eight_spade (13.7)	jack_diamond (9.59)	ace_diamond	ace_diamond
ace_club (60)	four_club (7.14)	five_spade (21.43)	seven_club (11.43)	ace_club	ace_club
ace_diamond (58.57)	eight_spade (10)	jack_diamond (21.43)	ten_club (10)	ace_diamond	ace_diamond
two_spade (20)	six_heart (17.14)	ace_club (57.14)	four_club (5.71)	ace_club	ace_club
six_diamond (19.44)	queen_club (15.28)	king_heart (56.94)	ten_diamond (8.33)	king_heart	king_heart
six_heart (26.09)	ace_club (56.52)	four_club (7.25)	five_spade (10.14)	ace_club	ace_club
four_diamond (21.13)	king_diamond (54.93)	six_club (14.08)	seven_diamond (9.86)	king_diamond	king_diamond
ten_spade (17.81)	nine_heart (17.81)	ace_spade (54.79)	queen_diamond (9.59)	ace_spade	ace_spade
king_heart (54.17)	ten_diamond (11.11)	five_diamond (19.44)	eight_club (15.28)	king_heart	king_heart
queen_club (15.94)	king_heart (53.62)	ten_diamond (18.84)	five_diamond (11.59)	king_heart	king_heart
three_club (19.72)	two_diamond (15.49)	jack_heart (53.52)	seven_heart (11.27)	jack_heart	jack_heart
seven_spade (21.74)	four_diamond (14.49)	king_diamond (52.17)	six_club (11.59)	king_diamond	king_diamond
four_club (11.27)	five_spade (22.54)	seven_club (14.08)	ten_heart (52.11)	ten_heart	ten_heart
king_diamond (52.05)	six_club (16.44)	seven_diamond (15.07)	nine_diamond (16.44)	king_diamond	king_diamond
three_spade (30)	two_club (10)	nine_club (8.57)	king_spade (51.43)	king_spade	king_spade
ten_heart (51.39)	three_spade (23.61)	two_club (12.5)	nine_club (12.5)	ten_heart	ten_heart
nine_heart (23.19)	ace_spade (50.72)	queen_diamond (14.49)	seven_spade (11.59)	ace_spade	ace_spade
seven_diamond (13.04)	nine_diamond (13.04)	jack_spade (50.72)	nine_spade (23.19)	jack_spade	jack_spade
four_spade (16.9)	six_diamond (14.08)	queen_club (18.31)	king_heart (50.7)	king_heart	king_heart
two_diamond (24.29)	jack_heart (50)	seven_heart (14.29)	four_heart (11.43)	jack_heart	jack_heart
nine_spade (18.06)	five_heart (18.06)	three_heart (13.89)	queen_heart (50)	queen_heart	queen_heart
jack_heart (50)	seven_heart (16.67)	four_heart (15.28)	eight_diamond (18.06)	jack_heart	jack_heart
queen_spade (49.3)	two_heart (22.54)	three_diamond (15.49)	five_club (12.68)	queen_spade	queen_spade
nine_club (15.49)	king_spade (49.3)	four_spade (14.08)	six_diamond (21.13)	king_spade	king_spade
two_club (15.94)	nine_club (17.39)	king_spade (49.28)	four_spade (17.39)	king_spade	king_spade
queen_heart (48.57)	jack_club (17.14)	two_spade (17.14)	six_heart (17.14)	queen_heart	queen_heart
ten_club (18.31)	king_club (47.89)	six_spade (19.72)	three_club (14.08)	king_club	king_club
jack_spade (47.89)	nine_spade (12.68)	five_heart (22.54)	three_heart (16.9)	jack_spade	jack_spade
five_spade (26.32)	seven_club (14.47)	ten_heart (47.37)	three_spade (11.84)	ten_heart	ten_heart
king_spade (47.3)	four_spade (17.57)	six_diamond (17.57)	queen_club (17.57)	king_spade	king_spade
nine_diamond (16.67)	jack_spade (47.22)	nine_spade (11.11)	five_heart (25)	jack_spade	jack_spade
five_diamond (17.33)	eight_club (18.67)	queen_spade (46.67)	two_heart (17.33)	queen_spade	queen_spade
jack_club (27.14)	two_spade (11.43)	six_heart (15.71)	ace_club (45.71)	ace_club	ace_club
six_club (15.07)	seven_diamond (16.44)	nine_diamond (23.29)	jack_spade (45.21)	jack_spade	jack_spade
king_club (44.59)	six_spade (12.16)	three_club (14.86)	two_diamond (28.38)	king_club	king_club
five_heart (24.29)	three_heart (15.71)	queen_heart (44.29)	jack_club (15.71)	queen_heart	queen_heart
queen_diamond (15.71)	seven_spade (24.29)	four_diamond (15.71)	king_diamond (44.29)	king_diamond	king_diamond
three_heart (23.19)	queen_heart (42.03)	jack_club (21.74)	two_spade (13.04)	queen_heart	queen_heart
seven_club (14.29)	ten_heart (41.43)	three_spade (30)	two_club (14.29)	ten_heart	ten_heart
six_spade (21.33)	three_club (17.33)	two_diamond (20)	jack_heart (41.33)	jack_heart	jack_heart
ten_diamond (20.55)	five_diamond (19.18)	eight_club (20.55)	queen_spade (39.73)	queen_spade	queen_spade
eight_club (21.13)	queen_spade (38.03)	two_heart (25.35)	three_diamond (15.49)	queen_spade	queen_spade
jack_diamond (26.76)	ten_club (18.31)	king_club (36.62)	six_spade (18.31)	king_club	king_club
eight_spade (23.19)	jack_diamond (31.88)	ten_club (18.84)	king_club (26.09)	jack_diamond	king_club

Figure 8.7 The Phoney app in operation.



Chapter 9

Conclusions and future work

This thesis set out to investigate ways in which optimal magic tricks could be produced, including the potential use of computational techniques and technologies that could be beneficially used in magic trick design and performance, and also how specific aspects of magical effects could be optimised using psychological observations. The intention was to build a conceptual framework capable of outputting novel and optimised tricks, by synthesising knowledge in three main areas:

1. Magic.
2. Psychology, as it relates to the perception and performance of magic.
3. Computer science, specifically AI techniques and computational creativity.

The framework also needed to provide an evaluation methodology that could convincingly provide some way of assessing the magical effects of the tricks outputted during the design phase.

9.1 Key questions answered

The key questions, as outlined in the introductory chapter (1), have been addressed:

1. *How can the human perceptual system be manipulated and affected by both external physical, and internal psychological, processes to produce magical effects?*

   The Association card trick directly showed how cognitive processes may be exploited for a magical effect. Experiments were conducted to gather data about strong mental associations made by people between images and words, and the mental categories that they belong to. These observations were made available to an algorithm that provided suggestions for a psychologically optimal magic trick that relied on the performer applying mild psychological pressure on the spectator, in order to activate their System 1 mental processes. The processes happen in a somewhat automatic way, allowing for a more reliable prediction to be made about the choices they make.

   The Crystal Ball trick relies on similar associative thinking, though exclusively about words and phrases. An algorithm similarly produced artefacts for use in a magic trick that had been subject to an optimisation process, taking into account cognitive aspects of words. The cognitive optimisations suggested by the algorithm were seen to be effective.

   The magic jigsaw trick provides evidence of how a number of different psychological factors may be exploited in one trick, with each being subject to empirical analysis and computational optimisation. The physical properties of the jigsaw itself were optimised to elicit a maximally magical effect, integrating both performance and perception issues. Empirical investigations into length perception were coupled with similar investigations into counting and jigsaw piece assembly. A GA, configured with various psychological and physical constraints, was successfully deployed to search the complex state space.

The combinatorial card trick exploits empirical data collected about the cognitive characteristics of playing cards. This data was used in an iterative optimisation process to design a probabilistic mind reading effect. Further, the use of technology as an in plain sight trick method, was investigated, and shown to be effective.

Generally, the framework provides a method for a trick designer to integrate psychological and physical observations, where necessary, into the design process of real world tricks.

2. *How can human perceptual and cognitive systems be modelled mathematically and/or computationally in order to optimise magical effects?*

The Association trick, detailed in chapter 6, relies on an underlying mathematical observation, the Gilbreath principle, for its operation. Further, the selection of the categories, and the words and images that make up the categories, is the result of computational assistance based on data derived from psychological experiments. Thus, the structure of the trick itself, and predictions about the cognitive processes at work during its operation, are modelled computationally, allowing for optimal categories, classes, and groups of categories to be automatically suggested.

The Crystal Ball trick, detailed in chapter 6, is modelled computationally as a tree structure, allowing an optimisation process to take place that evaluates the many different possible trees in terms of their cognitive (language based) and numerical (depth etc) properties. Predictions are made about optimal words and phrases to use that will maximise cognitive associations for a spectator; these predictive systems are based on experimentally determined data.

The Twelve Magicians of Osiris, detailed in chapter 7, is the result of the computational modelling of three separate perceptual and cognitive processes, based on empirically sourced data: the vertical-horizontal illusion, the counting of objects, and the cognitive load involved in jigsaw construction/perception of many jigsaw pieces. This data is used by a GA as a perceptual and cognitive model in its search for optimal jigsaw configurations.

The combinatorial card trick, detailed in chapter 8, uses an empirically derived model of the likeability of playing cards in its computational search for optimal decks of playing cards for use in the trick. Further, the experience of the trick is modelled by the observation that fewer questions during the fishing process results in a more magical experience. Decks of cards are modelled computationally in order to be used by a SA procedure that integrates physical and psychological constraints in its search process.

Generally, magic tricks may be modelled by collecting data with which to build a psychological model, and constructing, where possible, a mathematical/computational model of the trick. These models may then be used within a search and optimisation process as a way of evaluating candidate solutions.

3. *What are the implications of using modern computational devices, such as mobile phones, in magic performances?*

   The presentation of the Princess card trick on a mobile phone, detailed in chapter 5, established that it is a viable performance technique, that does not necessarily detract from the magical experience for a spectator.

   The Crystal Ball trick used a mobile phone as a performance device, and also as a kind of stand in for the memory of the performer, freeing them to concentrate on providing the narrative of the trick. Although a mechanism was provided for the performer to attempt to secretly pass information to the mobile phone, it was often detected by the spectators as being suspicious, though this did not lead them to determine its actual function, or the method of the trick.

   The combinatorial card trick, developed into the Phoney mobile phone app, provides the most fully developed use of computational technology in a trick discussed in the thesis. The phone operates as a cognitive memory aid to the performer, while also providing, by way of a faked passcode screen, a seemingly (according to the evaluations) invisible method of information passing. This is ideal for a performer. The spectators did not suspect the phone of being responsible for the magical effect.

The key finding is that use of modern technologies in magic performances does not necessarily detract from their magical impact. Any detected communication between the performer and the device has been shown to arouse suspicion. Similarly, any feeling on the part of the spectator that the phone is performing complex calculations, or using sophisticated sensors, can interfere with the performer's contention that something magical is happening. Ways to circumvent these problems have been described and shown to be successful.

4. *Can computational systems take on large areas of responsibility in the design process of a magic trick, towards being seen as creative entities in their own right?*

Both the Association and Crystal Ball tricks deployed computational systems that were used essentially as useful assistants in the design process of a magic trick. Their role was entirely sub-ordinate to the human trick designer. This is not to discount their usefulness. This kind of computational assistance can save a huge amount of time by quickly presenting options that may otherwise be unavailable, or difficult to access. Further, the suggestions provided by the systems, in the difficult to compute domain of natural language, were shown to be effective, and sometimes possessing a surprisingly ingenious quality.

The Twelve Magicians of Osiris was designed by an algorithm. This statement implies that the computer has moved from the role of an assistant to the role of a designer, a creative entity in its own right. The situation, however, is not so clear cut. While the artefact was in fact produced by a computational process, the computer was still configured, carefully, by a human designer. The problem domain was mapped out for the computer, the parameters defined, the constraints set, and all the decisions about which psychological models to use, and their meaning, was determined by a human. To describe the resulting artefact as the output of an autonomous creative entity seems far fetched.

Similarly, the decks designed for the combinatorial card trick were the result of an algorithm operating without further interference from a human. However, again, all the interference has occurred before the algorithm is run. The problem domain, the underlying trick itself, is designed by a human. All the decisions about how to categorise cards, which categories to use, the tuple length, the meaning of the depth properties of the tree structures, the very notion of likeability, are all human.

There is a case to be made for the algorithms used for the production of both the jigsaw trick, and the combinatorial card trick, to be seen as creative entities, though not a particularly strong one. Viewed as creative entities that are deploying a kind of exploratory creativity in an existing, known, search space, the algorithms can conceivably be compared to human trick designers operating in the same way. However, human designers are always capable of making leaps of imagination that take them out of the narrowly defined search space they may be engaged with, that computers, at least the algorithms presented in this thesis, are simply incapable of doing. Even if the capability to dynamically redefine their search space is programmed into them by a human, this merely redefines the limits within which they must operate; a human always has the capacity to imagine new limits.

5. *How can magic tricks be reliably evaluated?*

An evaluation and validation methodology has been proposed during the thesis that has been shown to effectively capture a number of features of magical experience in a practical and principled way. By combining the idea of enjoyment of a trick as a key measure, with the more qualitative factors gathered from word choices, a holistic picture of a spectator's experience of a trick can be built that neatly side steps difficult philosophical issues around the phenomenological aspects of magical experience.

Further, allowing spectators to report their suspicions, and to guess the methods behind a trick, allows the trick designer insight into areas of a trick that need refinement. These may be mechanical elements, or more theatrical aspects such as the particular narrative deployed.

Evaluating a trick in this way allows a direct comparison to be made with other tricks. Similarly, recording a spectator's general enjoyment of magic places their rating of a specific trick in context; some people simply do not enjoy magic performances, in the same way that some people simply do not enjoy reading novels. The overall success of a trick can be quite succinctly captured by calculating the average (mean) enjoyment rating reported for it by a group, and comparing this with the average (mean) rating the same group report for their enjoyment of magic in general.

Evaluating magic tricks is difficult, due to their highly subjective nature. There may be other methods that provide further insight. There is scope to more deeply probe the specifically magical nature of the experience of witnessing a magic trick. It may be that a magical experience is essentially binary: it either is, or isn't, experienced. The application of the evaluation methods outlined in this thesis does not produce a measure as to whether this magical experience occurs.

9.2 Framework benefits

The presented framework for magic trick creation provides a human designer with a novel way to approach trick design. The ability to integrate psychological observations, magical techniques, and sophisticated computational methods, in a way that allows the outputs to be reliably evaluated, provides a number of key benefits:

1. **Flexibility** Different configurations of a trick may be prototyped and tested. Impossible to achieve effects are easy to imagine; the viability of certain methods may be ruled in or out, in a principled way.

2. **Automation** The potential automation of the design process using a computer is of obvious benefit to a trick designer. Variations of tricks can be easily specified, and designed to order. Many variations can be quickly designed. New constraints can be introduced easily, allowing for new designs and approaches to be tried.

3. **Speed** The speed of the computational methods enables the feasible automation, and useful flexibility of the framework. Additionally, being able to work with ideas quickly is key for designers in many creative fields, including magic; rapid prototyping allows for iterative methods to be more easily applied.

4. **Extensibility** While the basic framework detailed here allows for the design, evaluation, and optimisation of a large range of tricks, it should also be noted that, due to the modular nature of the framework, elements can be easily added, or replaced, as the need arises. For example, additional evaluation techniques can be used if applicable to particular tricks, or new computational techniques integrated as they become available.

9.3 Framework problems

The main problem with the framework is its scope. For it to be fully exploited, each component must be integrated into a design process. This involves the performance of psychological experiments (or, at the minimum, the researching of relevant studies), the building of complex computational systems, and a rigorous evaluation phase. For many human trick designers, the amount of time and expertise required is unavailable.

A related problem is that some tricks are essentially unsuited to computational optimisation. While this leaves the framework still able to optimise the effects, as seen in chapter 5 with the Princess card trick, a major benefit is lost. Sometimes it is difficult to ascertain, at the beginning of the process, the viability of modelling certain tricks computationally. Thus, time can be expended on researching a trick, performing experiments and so on, before a conclusion is reached that it will not benefit from a computational model.

Finally, there is the question of the competition: human trick designers operating without a framework, computational or otherwise. All of the fantastic tricks throughout history have been designed and optimised solely by humans, more often than not operating in an intuitive, rather than scientifically rigorous, way. The need for a framework to intervene in this tradition is arguable, though it is hoped the benefits have been clearly mapped out over the course of the thesis. Human designers usually design tricks intuitively, using a natural feel for what will work and not work. This process is unarguably efficient and successful, and difficult to better.

9.4 Contributions

The main novel contributions of this thesis are:

1. The proposal and analysis of a new conceptual framework for the design, optimisation, and evaluation of magic tricks.

2. To the author's knowledge, the first use of AI for the design of magic tricks.

3. The proposal of a practical and principled approach to evaluating magic tricks.

9.5 Dissemination

All the tricks presented over the course of this thesis have been extensively shown to members of the public at all stages of the development process. The locations have been as diverse as the audiences: Big Bang science fairs (various locations throughout the UK), art installations in East London (Leandro Erlich: Dalston House), academic functions (Queen Mary University of London (QMUL) Cognitive Science Research Group opening party), and a research open day (QMUL), have all provided a rich mixture of subjects who were more than happy to take part in the evaluation phase of the framework, and were always delighted to be entirely honest in their appraisals. This has enabled both a kind of iterative feedback loop to be instigated between the intended audience and the trick designer, as discussed, and also as a way of presenting science and scientific methods to an interested group of people to initiate discussion, and generate interest in both magic and science.

This engagement of the public in computational ideas, psychological principles and experimental methods, and of course magic, has proved to be a reliably robust method of introducing relatively complex topics to those previously unaware of them. Using magic as a kind of explanatory tool has been both interesting for the performer, and hopefully useful for the spectators. Magic, as an art form, combines so much of science, art, and performance, that there is invariably something to discuss, even with those whose interest in magic is limited.

9.5.1 Reception

A report on the overall framework approach, along with summaries of the jigsaw trick and card trick detailed in chapters 7 and 8 respectively, was published in the journal Frontiers in Psychology, in a special issue: The Magic of Psychology and the Psychology of Magic [2]. Subsequently, the paper attracted a degree of media attention, which allowed the work to be viewed through a slightly different lens, and to gauge its reception among both the scientific and magic communities. Interviews were conducted with journalists, based on which articles were published. Four articles are discussed:

9.5.1.1 The Daily Mail

The Daily Mail newspaper in the UK ran an online article [252], by Sarah Griffiths, that provided an excellent summary for its readership, capturing some key elements from the paper:

> ...what the computer lacks in creativity, it makes up for in logic, because the tricks were created from maths rather than theatrics, using artificial intelligence in this way for the first time.

This quote neatly captures the difficulty of describing a computational process as a creative one. The notion of computational creativity, or lack of it, will doubtless continue to be debated.

Interestingly, the article chose to run with the theme that computers might one day replace human magicians; as should be clear, this is neither the intention nor claim of the work, though an understandable presentational technique for stories of this type. Dynamo, the famous UK based magician, was selected as the current exemplar magician who is purportedly under threat from the framework approach detailed here.

The idea that a computer could replace a human magician appears to be based on the concept of using a robot as a kind of stand in for the human magician. This is an interesting research theme in its own right, as it raises valid questions about how observers of magic tricks explain the causes of any given magical event. Currently, without the use of robots, human magicians are able to take the credit, and it is assumed that the absence of a human presence during the performance of a magic trick will rob the event of something quite fundamental to the process - that a performance of magic is taking place: something the human magician does causes the magical event, which somehow gives it a weight and mystery; the human magician has presumably had access to some secret knowledge unavailable to the observer. Replacing this human agency, along with the attendant complex social interactions that occur, with a robot, may reduce the experience to one of impressive mechanics, similar to witnessing a robot in a factory assembling a car. However, it may be that a magical event in the context of a performance is able to exist independently of human magicians, enabling the use of robotic stand ins; there may prove to be situations in which robot magicians would be able to exceed humans in producing a magical effect, due to their mechanical nature. Could the absence of human agency induce ever greater potentials for magic?

9.5.1.2 The Times

The Times newspaper in the UK also ran an article [253] summarising the work, and noting some of the results. The article focussed on the involvement of a computer in both the creation and performance of the tricks. The reporter (Hannah Devlin) was very curious about the methods behind the card trick, and presented an accurate summary of the paper:

> A good card trick relies on a magician's sleight of hand, psychological trickery and a charismatic presentation. Now, scientists have developed an algorithm that can optimise tricks and invent ones of its own - reducing the magic to pure science.

The type of work described in the paper (and this thesis) is inevitably going to raise some queries from both the magic and Artificial Intelligence communities. Richard Wiseman, professor of the public understanding of psychology at the University of Hertfordshire (and also a magician), described the concept as:

> Like getting a robot to put paint on a canvas and calling it art.

This appears to be based on a perception that the computers themselves were autonomously, once prompted, both designing and performing magic tricks. This was neither the intended aim, nor claim, of the work.

Wiseman further commented:

> Coming up with magic tricks is difficult, creative, and involves lateral thinking. The idea that a computer can have any insight into that is ridiculous.

While it is easy to agree with Wiseman that coming up with magic tricks is difficult, it is harder to agree with the implied notion that computers can provide no assistance to the process of their design. The belief that a computer has, itself, insight into anything at all is perhaps fundamentally erroneous, and is certainly not a claim made by the work presented here. Insight is arguably a facet of the phenomenon of consciousness, something that computers do not yet possess, and, conceivably, never will possess.

It should be clear from the work presented here that computers can provide human operators with all sorts of information, presented in ways that allow the operators to gain further insights of their own in to difficult problems. It has been extensively shown that computers, configured in the right way, can assist a human magic trick designer in a multitude of ways, enabling the discovery of solutions otherwise unavailable to them. It is a misunderstanding of the work to apprehend the computer itself as having insight into designing magic tricks.

During the course of this thesis, and the published paper, the difficulty of designing magic tricks has been discussed at length. The involvement of computers is presented as a potentially beneficial aid to trick designers and magicians, rather than as a replacement for them. It has been argued that the use of computers in magic, as well as many other fields, can provide a human designer with information that may lead them to greater insight into, and assistance with, difficult design problems, particularly when the computers are configured with psychological constraints derived from experimental data.

9.5.1.3 Scientific American

The popular science magazine Scientific American ran a similar article [254] to that in The Times, neatly summarising the work, though focussed overly on the computer's role in the performance of the tricks, sometimes leaning towards suggesting that a human performer was not involved (far from the truth). The journalist (Joshua A. Krisch) raised some interesting questions during the interview process, such as: "is this work ruining magic?", the answers to which were incorporated into the article.

It should be quite clear at this stage of the thesis, that ruining magic is neither the intention nor the outcome of the work. On the contrary, the focus is to improve magical effects. The question naturally arises, as the work deals with the scientific analysis of the components of a trick; it has been argued here that this is undertaken not to spoil the magical experience for spectators, by exposing its workings, but to maximise it.

The journalist canvassed the opinion of Ronald Graham, a mathematician with a keen interest in magic, working at the University of California, San Diego, who commented on the jigsaw trick:

> I think this will generate more discussion and more experiments. It'll be interesting to see what serious magicians think about the idea of using machine learning as a way to optimize the shapes of the rectangles.

More generally, Graham commented on the paper:

> It was a serious attempt to try to understand the whole impact of magic - why it impresses people and why it's amazing.

And on the topic of AI:

> Artificial intelligence has always been promising to do great things. This is just one avenue, where you try to use a computer's ability to look at thousands and millions and billions of cases and optimize what is it that fools people.

9.5.1.4 Inside Magic

The website Inside Magic, that describes itself as 'Magic News Updated Daily for the Professional Magician', ran an article by Tim Quinlan [255] discussing the publication of the paper, and its implications for the professional magician. This is of key interest, as the community of professional magicians forms a core part of the intended performers of the generated tricks. The report comments of the tricks:

> Both still require a real human [...] to perform and both are impressive.

and, further:

> We bought Phoney and have it on our Android device and are impressed by its method - not what one would think - and the way the creators have it hide on your phone. To be fair, it is a trick a magician could do without the AI but it is much easier and just as impressive to use one's phone.

This is useful feedback, further validating the outputs of the framework. While it is technically true that the card trick can be performed without the mobile phone, memorising a fifty two card deck (without any kind of mnemonically helpful ordering) is a difficult task, even for the dedicated. Memorising three decks (that the app provides), more so.

9.6 Future work

9.6.1 New tricks

There are many obvious avenues of further investigation and future work. Different types of trick to those discussed in this thesis present themselves quite clearly as being worthy of exploration:

1. **Stage magic** where the perceptual effects of shading or unusual body position may be modelled computationally, under constraints determined from experimental work. Often, in stage magic that deploys a human assistant, the assistant's body is worked into a position that is physically possible, but unexpected. The use, and optimisation, of relevant optical illusions suggests itself, as does an empirical investigation into perceived body shape behind obscuring objects (e.g. a body inside a box). Human designers currently use software packages to model the three dimensional problems inherent in this type of trick design; the addition of a more sophisticated approach that allows for the optimisation of the various parameters appears to be a natural fit for the framework approach.

2. **Large scale tricks** on social media platforms. The sheer volume of information currently available on the internet provides a ready-made source of psychological data. Social network theory [256] [257] is increasingly well understood, from a computational, psychological, and sociological perspective; combining these observations with magical techniques that involve confederates and third parties would appear to offer many opportunities for new magic.

3. **Close up magic** that relies on particular attributes of the human visual system, for example through the modelling of misdirection or sensory illusions. There is a body of research already available on the science of misdirection [77] [76], and illusions [231], as discussed in depth in chapter 2, that could be utilised and built upon. An exciting, though unexplored, prospect is a workable computational model of misdirection that would enable the conception and optimisation of a large number of new tricks. This could possibly be approached by constructing a model of visual gaze, and a model of distraction events, allowing various tests to be performed to verify the model, and subsequently allow the prediction of new tricks based on the reliable manipulation of a spectator's attention.

4. **Bayes.** There would appear to be a body of future research that could be fruitfully pursued investigating the human brain's apparent expectations of events, and cou-

pling these observations with recent advances in probabilistic graphical methods in computer science [258], for example Bayesian Networks, to both produce tricks and test our understanding of particular psychological processes. Viewing some magic tricks as an exercise in radically undermining a spectator's expectations - for example, a performer picks up a ball and closes their fist around it, only to later open the same fist, revealing an empty hand - reveals a possibility for computationally modelling, using Bayesian methods, the events that take place during the tricks. Applying these types of methods could lead to new ways to create effective magic, while simultaneously exploring the cognitive mechanisms underpinning the spectator's experience.

9.6.2 New scientific knowledge

The scientific study of magic is an active field of research, see Kuhn et al [52]. There appear to be ways to use magic as a kind of psychological probe, to throw light on the operation of the human brain: Rensink and Kuhn [54] propose an extensive framework for using magic to study the mind.

It is well known in neuroscience that injuries to the brain can provide evidence as to its normal workings. Studying what aspects of perception and cognition fail when certain areas of the brain are damaged can be instructive. Similarly, studying what areas of the brain are engaged, or otherwise, when the human perceptual and cognitive systems 'fail' during the experience of a magic trick may provide some insight to the operation of these systems.

There may be a fruitful area of research to be conducted using aspects of the presented framework in order to study perceptual and cognitive processes by designing specific magical effects. Analysing the efficacy, or otherwise, of such effects may illustrate underlying psychological processes - for example: expectation (seeing what we expect to see, even if it isn't there); false memories; various attention based processes. The optimisation methodology deployed to maximise magical impact may be alternatively utilised to find optimal experimental conditions for such studies.

9.6.3 New interfaces informed by magic

This thesis has outlined ways in which the framework can be deployed to generate and optimise magic tricks, that are intended to deceive spectators in various ways. Additionally, the framework may prove of use, with some remodelling, as a way to ensure that people are *not* fooled.

Making mistakes, both perceptual and cognitive, as we have seen over the course of this thesis, is a normal part of every day human activity; unfortunately, human beings operating in a medical context still exhibit normal human behaviours, including making errors, as Kohn et al [259] make clear.

User interface design, particularly in the field of medical devices, demands precision, simplicity, and clarity; medical errors cost lives. There have been some efforts to engineer better, safer, medical device interfaces, that go some way to eradicating the possibility for human error; see Zhang et al [260]. These have often been based on adapting user interface design methods from other fields.

Applying the framework presented here, but with different goals, could prove useful in this area of user interface design. Breaking an interface down into both psychological, and physical/layout, components should allow the application of a similar design and optimisation process used for the magic tricks, but instead of optimising the level of deception achieved, the number of errors produced by an interface could be minimised.

The jigsaw trick discussed in chapter 7 provides a glimpse of the type of issues likely to be encountered: the layout of an interface, with a number of component pieces making up the whole, has an obvious similarity to the jigsaw's pieces, while the content displayed on each element of the layout can be seen as the rectangular objects on its surface; differing layouts and content are likely to have a direct impact on the perception of the interface, which could be subject to similar experimental methods and subsequent constraints in any derived computational system.

9.7 Conclusion

A general framework approach to designing and evaluating new magic tricks has been introduced and analysed over the course of this thesis. The framework describes a method to integrate empirical data about human perception and cognition with computational techniques to create effects previously challenging for a human trick designer to produce. The framework also provides a practical, principled way to objectively evaluate the output of the creation process. This general approach to trick design is highly flexible and applicable to many different types of trick.

Three case studies that adapted the framework to specific types of trick have been described. Each use of the framework resulted in a novel effect that was proven to be effective in real life scenarios.

The tricks created by the framework were accepted for inclusion in the inventory of a reputable magic shop in London, and made available as mobile phone apps at the Google Play store. A copy of the jigsaw product is also archived in the library of the Magic Circle in London.

In conclusion, it has been shown that effects with significant magical impact can be implemented on, and by, computing devices. It might be expected that sophisticated technology in a performance would be incapable of producing a magical effect, as any seemingly impossible events could be easily attributable to the computer. On the contrary, a new and wide range of possible effects intertwining the real and the virtual may be available to the modern magician with the right tools.

Chapter 10

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Appendix A

Association trick algorithms

Algorithm 1 AssociationTrick. Generates candidate sets of categories and words for use in the Association trick.

Inputs: [Theme]

$dictionary \leftarrow GetEnglishDictionary()$ ▷ list of words in English language
$documentStore \leftarrow GetDocumentStore(Theme)$
$categories \leftarrow GetCategories(documentStore, dictionary)$
$categoriesAndWords \leftarrow GetSuggestedWords(categories, dictionary)$
$solution \leftarrow categoriesAndWords$
return $solution$

Algorithm 2 GetDocumentStore. Generates the document store.

Inputs: [Theme]

$documentStore \leftarrow LoadAnyDocumentStore()$ ▷ loads any existing document stores, e.g. those derived empirically
for all $Class$ in $Theme$ **do**
    $document \leftarrow NewDocument(Class)$
    $query \leftarrow$ 'Class + Theme'
    $urls \leftarrow InternetSearch(query)$ ▷ top ten search results for query
    for all url in $urls$ **do**
        $text \leftarrow GetText(url)$ ▷ all text found at url
        $document.Append(text)$
    end for
    $documentStore.Add(document)$
end for
return DS

Algorithm 3 GetCategories. Generates categories from the document store.

Inputs: [documentStore, dictionary]

$categories \leftarrow NewCategories()$
$reducedDictionary \leftarrow removeLowICWords(dictionary)$ ▷ removes low information content words
for all $word$ in $reducedDictionary$ **do**
  $scores \leftarrow NewScores()$
  for all $document$ in $documentStore$ **do**
    $query \leftarrow word$
    $score \leftarrow BM25(document, query)$
    $scores.Add([document, score])$
  end for
  $scores \leftarrow SortByDescendingScore(scores)$
  $topFourClassess \leftarrow GetTopFour(scores)$ ▷ the top four document classes for this word
  $categories.Add([word, topFourClasses])$
end for
$conceptuallySeparatedCategories \leftarrow GetBestSeparated(categories)$
return $conceptuallySeparatedCategories$

Algorithm 4 GetBestSeparated. Finds set of categories that are, conceptually, least similar.

Inputs: [categories]

$bestSeparatedCategories \leftarrow GetEmptyList()$ ▷ unknown initially
$lowestSimilarityScore \leftarrow Integer.MaxValue$
$n \leftarrow 20$
$r \leftarrow 7$
$combinations \leftarrow GetCombinations(n, r)$ ▷ picks all combinations of 7 categories from the top 20
for all $combination$ in $combinations$ **do**
  $similarityScore \leftarrow GetSimilarityScore(combination)$
  if $similarityScore < lowestSimilarityScore$ **then**
    $lowestSimilarityScore \leftarrow similarityScore$
    $bestSeparatedCategories \leftarrow combination$
  end if
end for
return $bestSeparatedCategories$

Algorithm 5 GetSimilarityScore. Scores a set of categories for semantic similarity.

Inputs: [categories]

$score \leftarrow 0$
for all $category1$ in $categories$ **do**
  for all $category2$ in $categories$ **do**
    if $category1 <> category2$ **then**
      $score \leftarrow score + word2vec.Similarity(category1.Word, category2.Word)$ ▷ the word2vec tool loaded with an appropriately trained model
    end if
  end for
end for
return $score$

Algorithm 6 GetSuggestedWords. Expands words associated with categories, using the classes within each category.

Inputs: [categories, dictionary]

$categoriesAndWords \leftarrow EmptyList()$ ▷ unknown initially
for all $category$ in $categories$ **do**
  $words \leftarrow GetWords(category, dictionary)$
  $categoriesAndWords.Add([category, words])$
end for
return $categoriesAndWords$

Algorithm 7 GetWords. Finds top scoring words for each document in a category.

Inputs: [category, dictionary]

$reducedDictionary \leftarrow removeLowICWords(dictionary)$
$wordScores \leftarrow EmptyList()$ ▷ unknown initially
for all $word$ in $reducedDictionary$ **do**
  $query \leftarrow word$
  for all $document$ in $category$ **do**
    $score \leftarrow BM25(document, query)$
    $wordScores.Add([word, score])$
  end for
end for
$wordScores \leftarrow SortByDescendingScore(wordScores)$
$wordScores \leftarrow GetTop32DistinctWords(wordScores)$
return $wordScores$ ▷ returns 32 words that score highly against documents in the inputted category

Appendix B

Crystal Ball trick algorithms

Algorithm 8 BranchingAnagram. Generates tree structures for use in the Crystal Ball trick.

Inputs: [theme]

$knowledgeMap \leftarrow GetKnowledgeMap(theme)$ ▷ Retrieve relevant knowledge map
$names \leftarrow GetNames(theme)$
$bestTree \leftarrow EmptyTree()$
$bestScore \leftarrow 100000.0$
for all $letter$ in $alphabet$ **do**
  $tree \leftarrow GenerateTree(letter, names)$
  $score \leftarrow ScoreTree(tree, knowledgeMap)$
  if $score < bestScore$ **then**
    $bestScore \leftarrow score$
    $bestTree \leftarrow tree$
  end if
end for
return $bestTree$

Algorithm 9 GenerateTree. Generates trees for use in the Crystal Ball trick.

Inputs: [letter, names]

$tree \leftarrow EmptyTree()$
$depth \leftarrow 0$
$alphabet \leftarrow GetEnglishAlphabet()$
$root \leftarrow GenerateNode('root', letter, names, depth, alphabet)$
$tree.Add(root)$
return $tree$

Algorithm 10 GenerateNode. Generates a node in a tree.

Inputs: [nodetype, letter, names, depth, alphabet]

```
node ← NewNode()
children ← EmptyList()
if nodetype ≠ root then
    alphabet.Remove(letter)
end if
depth ← depth + 1
if Length(names) = 1 then                          ▷ A leaf node has been reached
    return
end if
if depth = 26 then          ▷ All 26 letters of the alphabet have been processed
    return
end if
options ← EmptyList()
for all optionLetter in alphabet do
    namesYes ← AllNamesWithLetter(optionLetter)
    namesNo ← AllNamesWithoutLetter(optionLetter)
    score ← Length(namesYes)/Length(names)
    if Length(namesYes) < Length(names) AND Length(namesNo) < Length(names)
then
        options.Add([optionLetter, score, namesYes, namesNo])
    end if
end for
if Length(options) > 0.0 then
    options.SortByScore()
    highscore ← options.GetHighestScore()
    if nodetype = root then
        options ← options.FilterByScore(highscore)
        options ← options.FilterByLetter(letter)
    else
        options ← options.FilterByScore(highscore)
    end if
    for all o in options do
        optionLetter ← o.GetLetter()
        namesYes ← o.GetNamesYes()
        namesNo ← o.GetNamesNo()
        if Length(namesYes) > 0 then
            children.Add(GenerateNode('yes', optionLetter, namesYes, depth, alphabet)
        end if
        if Length(namesNo) > 0 then
            children.Add(GenerateNode('no', optionLetter, namesNo, depth, alphabet)
        end if
    end for
end if
node.Add(children)
return node
```

Algorithm 11 CostTree. Evaluates the cost of a tree. Lower costs are better.

Inputs: [tree, knowledgeMap]

$cost \leftarrow 0$
$routeMaps \leftarrow GetRouteMaps(tree)$ ▷ Returns a set of route maps, each containing a set of routes that enables each word in the theme to be reached in one distinct way.
for all $routeMap$ in $routeMaps$ **do**
  $routeMapCost \leftarrow 0$
  for all $route$ in $routeMap$ **do**
    $routeCost \leftarrow CostRoute(route, knowledgeMap)$
    $routeMapCost \leftarrow routeMapCost + routeCost$
  end for
  $routeMap.SetCost(routeMapCost)$
end for
$bestRouteMap \leftarrow routeMaps.GetLowestCostRouteMap()$
$cost \leftarrow bestRouteMap.GetCost()$
return $cost$

Algorithm 12 CostRoute. Evaluates the cost of a route, defined by how well the 'no' nodes can be explained from the knowledge map. 'Yes' nodes are seen as having zero cost.

Inputs: [route, knowledgeMap]

$cost \leftarrow 0$
for all $node$ in $route$ **do**
  $letter \leftarrow node.GetLetter()$
  $namesNo \leftarrow node.GetNamesNo()$
  $nodeCost \leftarrow 0$
  for all $name$ in $names$ **do**
    $explainingWord \leftarrow knowledgeMap.GetWord(letter, name)$ ▷ Finds a word, if it exists, in the knowledge map that starts with the given letter, and is associated with the given name
    $wordCost \leftarrow 1.0 - word2vec.Similarity(name, word)$ ▷ the word2vec tool loaded with an appropriately trained model
    $nodeCost \leftarrow nodeCost + wordCost$
  end for
  $cost \leftarrow cost + nodeCost$
end for
return $cost$

Appendix C

Jigsaw trick algorithms

Algorithm 13 DesignJigsaw. Generates optimised magical jigsaw designs with a NSGA-II derived Genetic Algorithm using rectangle packing techniques.

Inputs: [numberOfGenerations, populationSize, mutationRate, crossoverRate]

$P \leftarrow InitialisePopulation(populationSize)$
$P \leftarrow SortAndRank(P)$
$Q \leftarrow TournamentSelection(P, mutationRate, crossoverRate, populationSize)$
$generation \leftarrow 0$
while $generation < numberOfGenerations$ **do**
    $Q.EvaluateFitnessOfIndividuals()$
    $R \leftarrow P + Q$
    $R \leftarrow SortAndRank(R)$
    $P \leftarrow GetFittest(R, populationSize)$
    $Q \leftarrow TournamentSelection(P, mutationRate, crossoverRate, populationSize)$
    $generation \leftarrow generation + 1$
end while
$solution \leftarrow GetFittest(Q, 1)$
return $solution$

Algorithm 14 InitialisePopulation. Initialises a set of candidate jigsaw solutions.

Inputs: [populationSize]

$population \leftarrow EmptyPopulation()$
$i \leftarrow 0$
while $i < populationSize$ **do**
    $numberOfPieces \leftarrow RandomNumber(5, 16)$
    $pieces \leftarrow RectanglePack(numberOfPieces)$ ▷ Randomly chooses and packs a set of pieces
    $numberOfObjects \leftarrow RandomNumber(4, 16)$
    $individual \leftarrow GenerateBinaryString(pieces, numberOfObjects)$
    $population.Add(individual)$
    $i \leftarrow i + 1$
end while
$population.EvaluateFitnessOfIndividuals()$
$population.SortByFitness()$
return $population$

Algorithm 15 SortAndRank. Sorts and ranks a population into non-dominated fronts.

Inputs: [population]

$populationSize \leftarrow Size(population)$
$fronts \leftarrow FastNondominatedSort(population)$
$fronts.AssignCrowdingDistance()$
$parents \leftarrow Empty()$
for all $front$ in $fronts$ **do**
    if $(Size(parents) + Size(front)) > populationSize$ **then**
        $from \leftarrow 0$
        $to \leftarrow (Size(parents) + Size(front)) - populationSize$
        $parents.Add(front.GetIndividuals(from, to))$
        Break
    else
        $from \leftarrow 0$
        $to \leftarrow Size(front)$
        $parents.Add(front.GetIndividuals(from, to))$
    end if
end for
return $parents$

Algorithm 16 FastNondominatedSort. Sorts a population into ranked Pareto fronts.

Inputs: [population]

$front \leftarrow EmptyList()$
for all p in $population$ **do**
  $p.Sp \leftarrow EmptyList()$
  $p.np \leftarrow 0$
  for all q in $population$ **do**
    if $p.Dominates(q)$ **then**
      $p.Sp.Add(q)$
    end if
    if $q.Dominates(p)$ **then**
      $p.np \leftarrow p.np + 1$
    end if
  end for
  if $p.np = 0$ **then**
    $p.NonDominationRank \leftarrow 1$ ▷ Sets the rank of the referenced individual in the population
    $front.Add(p)$
  end if
end for
$i \leftarrow 1$
while $Size(front > 0$ **do**
  $Q \leftarrow EmptyList()$
  $j \leftarrow 0$
  for all $pfinfront$ **do**
    for all q in $pf.Sp$ **do**
      $q.np \leftarrow q.np - 1$
      if $q.np = 0$ **then**
        $q.NonDominationRank \leftarrow i + 1$ ▷ Increments the rank of the referenced individual in the population
        $Q.Add(q)$
      end if
    end for
    $j \leftarrow j + 1$
  end for
  $i \leftarrow i + 1$
  $front = Q$
end while
return $population$

Appendix D

Card trick algorithms

Algorithm 17 Simulated Annealing Deck Search. The SA algorithm; searches for a cyclical deck that satisfies user specified criteria.

CATS: Categories
n: Tuple length
α: Annealing rate

$CATS \leftarrow GetCategorySet()$ ▷ Categories e.g. [Colour, Likeable]
$n \leftarrow GetTupleLength()$ ▷ Tuple length, e.g. 4 cards
$\alpha \leftarrow 0.999995$
$deckSize \leftarrow GetDeckSize()$ ▷ e.g. 52
$startTemperature \leftarrow 1000$
$time \leftarrow 0$
$currentTemperature \leftarrow 0$
$deck \leftarrow RandomShuffledDeck(deckSize)$
while $currentTemperature > 0.0001$ **do**
  $currentTemperature \leftarrow startTemperature \times \alpha^{time}$
  $nextDeck \leftarrow SwapTwoRandomCards(deck)$
  $E \leftarrow Score(nextDeck, CATS, n) - Score(deck,\ CATS,\ n)$
  if $E > 0$ **then**
    $deck \leftarrow nextDeck$
  else
    $p \leftarrow e^{E/currentTemperature}$
    $r \leftarrow RandomNumber(0.0, 1.0)$
    if $r < p$ **then**
      $deck \leftarrow nextDeck$
    end if
  end if
  $time \leftarrow time + 1$
end while
$solution \leftarrow deck$
return $solution$

Algorithm 18 Score. The deck is scored based on the number of singular card tuples at the leaf nodes of its associated tree, and any additional user specified constraints.

Require: *deck*, Category sets *CATS*, Tuple length n
  $tree \leftarrow GenerateTree(deck, CATS, n)$
  $score \leftarrow 0$
  for $startIndex = 0$ to $deckSize - 1$ **do**
    $tuple \leftarrow GetTuple(deck, startIndex, n)$ ▷ n consecutive cards, wrapping
    if tree.AtLeaf(*tuple*) AND ConstraintsSatisfied(*tuple*) **then**
      $score \leftarrow score + 1$
    else
      return *score*
    end if
  end for
  return *score*

Algorithm 19 Generate Tree. Generates a tree structure from a deck of playing cards based on category sets and tuple length specified.

Require: *deck*, Category sets *CATS*, Tuple length n
  $tree \leftarrow NewTree()$
  $root \leftarrow AllTuples(deck, n)$
  tree.AddChild(*root*)
  for each *category* in CATS **do**
    $tree \leftarrow CalculateChildNodes(tree, category, n)$
  end for
  return *tree*

Algorithm 20 Calculate Child Nodes. Finds leaf nodes with multiple tuples and adds child nodes based on category.

Require: *tree*, *category*, Tuple length n
  for each *leafNode* in *tree* **do**
    for each *categoryPermutation* in *category* **do**
      $node \leftarrow NewNode(categoryPermutation)$
      for each *tuple* in *leafNode* **do**
        if *tuple*.GetPermutation(*category*) = *categoryPermutation* **then**
          node.Add(*tuple*)
        end if
      end for
      leafNode.AddChild(*node*)
    end for
  end for
  return *tree*